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THIS NUMBER COMPLETES VOLUME XVII

VOL. XVII JUNE, 1924 No. 6

JUL 25 1924

SOIL SCIENCE

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PUBLISHED MONTHLY BY

WILLIAMS & WILKINS COMPANY

BALTIMORE, MD., U. S. A.

Entered as second-class matter May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879

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Price per volume, net post paid { $5.00, United States, Canada, Mexico, Cuba
$5.50, other countries

Made in United States of America

SOIL SCIENCE

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ERRATA

The Absorption of Ions by Plants, by D. R. Hoagland. Soil Science, vol. XVI, no. 4, October, 1923, pp. 225–246.

Table 1 and following tables, columns headed "atm." should read "milli-equivalents."

Page 245, summary, paragraph 5, line 2 should read "increases" instead of "decreases".

THE EFFECT OF SEVERAL MINERAL FERTILIZERS UPON THE NODULATION OF VIRGINIA SOY BEANS[1]

ALFRED T. PERKINS[2]

New Jersey Agricultural Experiment Stations

Received for publication January 8, 1924

Among the outstanding data on the effect of mineral fertilizers upon the nodule-forming organisms and their symbiotic relationship with legumes are those of Prucha (6), Wilson (8), Fellers (2), and Heinze (5). Prucha found that elements essential for plant growth greatly increased nodulation when applied in small amounts. Wilson observed that an application of these elements would aid the symbiotic relationship. Fellers found that under many conditions nodulation was increased by an application of phosphorus, calcium, or potassium. Heinze found that the addition of phosphorus or potassium to a soil had little if any effect upon its content of symbiotic nitrogen fixing organisms. The author concluded after a review of the literature and in consideration of some data collected in 1920–1921 (experiment 1 of this paper) that elements essential for plant growth have little, if any direct effect upon the infection and nodulation of leguminous crops. The work reported in this paper was outlined to determine what effect the essential elements would have upon nodulation when the unknown factors were reduced to a minimum and all known factors controlled as far as possible.

SCOPE

This paper reports a study of the effect upon nodulation of the four essential elements most likely to be limiting factors. These elements were applied as calcium carbonate, potassium chloride, sodium nitrate, and acid phosphate; except in experiment 1 where sodium phosphate was used. All conditions were controlled as much as possible under green house conditions. Experiment 1 is a study of the effect upon nodulation of calcium, potassium, and phosphorus when they were applied according to the triangle plan as frequently used by Schreiner and others. Experiments 2–5 are studies of the effect upon

[1] Paper No. 161 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology.

Part of a thesis submitted to the faculty of Rutgers College in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] The author takes pleasure in expressing his gratitude to Dr. J. G. Lipman for general guidance in carrying out this work and to Prof. A. W. Blair, Dr. J. W. Shive, and Dr. S. A. Waksman for many helpful suggestions.

nodulation of increasing applications of phosphate, potassium, calcium,and nitrate respectively. Several different substrata were used and they were maintained at different degrees of saturation.

METHODS

Wherever possible standard methods were employed.

Inoculation was always accomplished by mixing the emulsions obtained from the growth upon agar slants of three separate strains of *Bacillus radicicola*. The emulsions were obtained by scraping the growth free from the agar with a platinum needle, shaking vigorously with a small quantity of sand and then transfering aliquot parts to the several pots. Care was always taken to add a sufficiently large number of organisms to insure that maximum nodulation would not be prevented by a lack of the infecting organisms. By using three strains of the organism the presence of a viable culture has been more definitely assured.

After washing the white quartz sand used, it was exposed to the sunlight until air-dried to assure the absence of nodular organisms.

A uniform plant stand was obtained by sowing twenty seeds to the pot and thinning the resulting seedlings to ten per pot.

Application of fertilizers was made whenever possible by means of solution and aliquot parts. With insoluble materials, the fertilizer was usually weighed out for each application.

Hydrogen-ion determinations were made colorometrically according to the method outlined by Gillespie (4). Generally the determinations were made on only one of duplicate pots.

The water-holding capacity of the various substrata was determined by the use of Hilgard cups.

The chemical methods employed in determining the soluble material in the various substrata were in general the methods of the Association of Official Agricultural Chemists (1). In a few cases other methods were used.

The harvests were made at the end of four weeks of growth.

Nodular counts were made after freeing the roots of the host from the substratum by gently washing them in water.

The mechanical determinations were made according to the method of the United States Bureau of Soils (3).

EXPERIMENT 1. RELATIVE NODULATION FROM TREATMENT IN ACCORDANCE WITH THE, "TRIANGLE PLAN"

In attempting to determine the fertilizing mixture which would be most favorable to the nodulation of legumes it was decided to apply several fertilizers on a triangular basis. A general survey of the literature seemed to indicate that the desired fertilizing mixture would be approached by an application of one ton per acre of a nitrogen-free fertilizer containing calcium. Accordingly the fertilizers applied were calcium carbonate, potassium chloride, and sodium phosphate. A total application of one ton per acre was made and the increments were two hundred pounds each. Each pot received also a small amount of magnesium and ferrous sulfates. By this system twenty-one pots receiving different fertilizing applications were set up. The applications made are listed in table 1. The crop was grown in three-pound pots filled with washed sand which was maintained at 75 per cent saturation by daily waterings with

distilled water. The results obtained show that when lime is absent or present in only small amounts nodulation is greatly limited. With the exception of this limitation in the absence of lime all the pots gave approximately equal nodulation. The conclusion drawn is that the salt balance has little effect on nodulation when there is a small amount of lime present. The results given are those for *Virginia* soy beans, but as other varieties of soy beans as well as

TABLE 1

Nodulation as affected by various fertilizers

POT NUMBERS	FERTILIZER FORMULA			NUMBER OF NODULES PER 10 PLANTS	WEIGHT OF AIR-DRIED TOPS PER 10 PLANTS
	$CaCO_3$	KCl	NaH_2RO_4		
	proportional parts				*gm.*
1–1	0	0	10	10	0.693
1–2	0	2	8	25	0.781
1–3	0	4	6	14	0.803
1–4	0	6	4	31	0.678
1–5	0	8	2	26	0.779
1–6	0	10	0	18	0.825
2–1	2	0	8	103	0.807
2–2	2	2	6	60	0.735
2–3	2	4	4	83	0.678
2–4	2	6	2	75	0.902
2–5	2	8	0	86	0.857
3–1	4	0	6	87	0.739
3–2	4	2	4	79	0.803
3–3	4	4	2	62	0.909
3–4	4	6	0	97	0.917
4–1	6	0	4	93	0.813
4–2	6	2	2	85	0.792
4–3	6	4	0	59	0.697
5–1	8	0	2	74	0.761
5–2	8	2	0	68	0.661
6–1	10	0	0	80	0.803

other leguminous crops gave similar results it may be assumed that the results obtained throughout the work will hold in a general way for all leguminous crops.

EXPERIMENT 2. EFFECT OF PHOSPHATE UPON NODULATION

By varying only a single fertilizer the effect of its absence or presence in excess may be determined if all other elements are present in amounts favorable to nodulation and plant growth. Acid phosphate was applied at rates vary-

ing from nothing to three thousand pounds per acre. Applications were made to three different substrata and each substratum was maintained at four different degrees of saturation. The substrata used were washed sand, sassafras

TABLE 2

Effect of increasing applications of acid phosphate upon nodulation

SATURATION OF SUBSTRATUM	ACID PHOSPHATE APPLIED PER ACRE*	REACTION OF SUBSTRATUM AFTER 2 WEEKS' GROWTH AND NUMBER OF NODULES PER TEN PLANTS AFTER 4 WEEKS' GROWTH								
		Washed sand			Penn loam			Sassafras loam		
		First	Second	pH	First	Second	pH	First	Second	pH
per cent										
25	0	52	45	6.8	8	9	5.3	27	25	6.4
	50	43	40	6.7	6	8	5.5	30	10	6.6
	250	23	25	6.6	1	1	5.5	85	70	6.6
	500	18	15	6.7	1	2	5.5	33	30	6.6
	1,000	8	8	6.4	0	0	5.5	27	25	6.6
	2,000	2	2	6.5	0	0	5.5	0	0	6.8
	3,000	0	0	6.6	0	0	5.3	27	25	6.5
50	0	80	60	6.6	24	26	5.2	55	60	6.5
	50	67	60	6.7	18	20	5.5	45	50	6.6
	250	36	36	6.7	15	12	5.3	35	60	6.6
	500	33	29	6.7	12	12	5.5	30	†	6.8
	1,000	21	20	6.5	6	5	5.7	40	†	6.5
	2,000	7	5	6.5	0	0	5.3	70	70	6.6
	3,000	0	0	6.6	0	0	5.6	10	10	6.5
75	0	80	90	6.5	30	24	5.5	90	†	6.6
	50	70	60	6.8	45	50	5.4	†	†	6.8
	250	50	52	6.7	25	24	5.3	51	30	6.6
	500	36	32	6.8	27	26	5.7	83	60	6.6
	1,000	23	22	6.5	10	10	5.5	90	†	6.7
	2,000	11	12	6.6	0	0	5.5	95	80	6.8
	3,000	2	3	6.4	0	0	5.7	†	†	6.6
100	0	60	50	6.6	0	0	5.8	†	†	7.2
	50	100	85	6.7	60	70	5.9	†	†	7.2
	250	60	55	6.8	30	30	5.8	†	†	6.8
	500	42	33	6.8	30	32	5.7	†	†	6.8
	1,000	30	32	6.6	21	20	5.6	†	†	6.8
	2,000	13	15	6.7	0	0	5.6	†	†	6.8
	3,000	0	0	6.6	0	0	5.8	†	†	6.8

* Pots containing washed sand as a substratum received a general fertilizer application of:

	pounds per acre
Magnesium sulfate	15
Ferrous sulfate	10
Potassium hydroxide	61
Calcium carbonate	500

† Indicates that no plant growth was obtained.

loam, and Penn loam which were respectively 99.36, 70.23 and 47.10 per cent sand. The plant food in the substrata varied almost directly with their fineness. Largely as a result of their mechanical composition the soils differed in their water-holding capacities, which were 25, 35, and 68 per cent respectively. The acid phosphate was applied to the several substrata at the rates indicated in table 2. These applications caused the soils to have contents of available phosphate varying from the absolute minimum to an excess far beyond that which is reached in good farming practice. In the case where no phosphate was added to the washed sand it is estimated that there was present less than two pounds of available phosphate per acre which represents that in the seeds. In the case of the washed sand a general fertilizer application was made to all the pots as indicated in table 2. The data collected indicate that equal applications of phosphate do not have the same effect upon nodulation when the plants are grown in different substrata. This was naturally to be expected as the various substrata differed greatly in their properties. In the case of the washed sand where unknown factors were at a minimum the maximum nodulation was obtained when no phosphate was applied. This is taken as an indication that phosphate is not essential for nodulation. With the sand as a substratum the decreasing nodulation with increasing applications of phosphate is attributed to an increased osmotic pressure, or some similar factor. No attempt was made to explain the erratic results obtained when sassafras loam was the substratum. They are presented to emphasize the point that in soils many unknown factors play a part in the process of nodulation. In the pots where no plant growth was obtained germination was prevented by the high water content. The results obtained with Penn loam agree very well with the results obtained with the washed sand even though the Penn loam contained a large amount of phosphorus at the start.

The conclusion drawn is that phosphate is not essential for the nodulation of young soy bean plants. In connection with this conclusion it should be born in mind that soy beans are good foragers for phosphate. A close relation between root development and nodulation was noted as they increased and decreased together.

EXPERIMENT 3. EFFECT OF POTASH UPON NODULATION

This experiment was similar to experiment 2. Potassium, as the varying element, was applied as potassium chloride at rates of 0, 50, 250, 500, 1000, and 3000 pounds per acre. The substratum used was washed sand maintained at four different degrees of saturation. The washed sand only was used as a substratum as the data obtained from the true soils was considered to be of scant value. From the number of nodules appearing upon the roots of the several plants it may be assumed that the presence of potassium is unnecessary for maximum infection to occur. It would appear that in the series maintained at maximum saturation small applications of potash aided nodulation; but as

the increase is not greater than the experimental error it is of doubtful significance. Applications of potassium chloride up to and including 500 pounds per acre had no appreciable effect upon nodulation and greater applications inhibited the symbiotic relationship. This toxicity is probably due to an excess

TABLE 3

Effect of increasing applications of potassium chloride upon nodulation

POT NUMBER	SATURATION OF SUBSTRATUM	POTASSIUM CHLORIDE APPLIED PER ACRE*	REACTION OF SUBSTRATUM AFTER 2 WEEKS' GROWTH	NUMBER OF NODULES PER 10 PLANTS		AVERAGE WEIGHT AIR-DRY TOPS
				First	Second	
	per cent	*pounds*	*pH*			*gm.*
1 A	25	0	6.6	60	65	0.96
2 A	25	50	6.4	56	53	0.97
3 A	25	250	6.6	53	67	1.19
4 A	25	500	6.7	40	48	1.23
5 A	25	1,000	6.5	32	38	1.05
6 A	25	3,000	6.7	0	0	†
1 B	50	0	6.5	75	91	1.03
2 B	50	50	6.6	86	80	1.19
3 B	50	250	6.6	73	93	1.36
4 B	50	500	6.6	85	73	1.46
5 B	50	1,000	6.7	65	70	1.39
6 B	50	3,000	6.7	0	0	†
1 C	75	0	6.7	72	84	1.07
2 C	75	50	6.7	83	80	1.27
3 C	75	250	6.5	69	92	1.69
4 C	75	500	6.5	80	87	1.88
5 C	75	1,000	6.8	71	79	1.72
6 C	75	3,000	6.8	0	0	†
1 D	100	0	6.5	97	95	1.35
2 D	100	50	6.5	90	103	1.45
3 D	100	250	6.6	98	92	1.62
4 D	100	500	6.7	93	107	2.01
5 D	100	1,000	6.7	101	118	1.88
6 D	100	3,000	6.6	30	42	1.25

* All pots received a general fertilizer application of:

	pounds per acre
Magnesium sulfate	15
Ferrous sulfate	10
Calcium carbonate	500
Phosphoric acid	108

† Scant growth obtained.

of the potassium or chlorine ion, the high osmotic pressure or some similar factor.

The conclusion reached is that applications of potash are not necessary for maximum nodulation.

EXPERIMENT 4. EFFECT OF LIME UPON NODULATION

This experiment was similar to experiments 2 and 3 with calcium as the varying element. The calcium was applied to washed sand at rates of 0, 50, 250, 500, 1000, 3000, and 5000 pounds per acre. The sand was fertilized as

TABLE 4

Effect of increasing applications of calcium carbonate upon nodulation

POT NUMBER	SATURATION OF SUB-STRATUM	CALCIUM CARBONATE APPLIED PER ACRE*	REACTION OF SUBSTRATUM AFTER 2 WEEKS' GROWTH	NUMBER OF NODULES PER 10 PLANTS		AVERAGE WEIGHT AIR-DRY TOPS
				First	Second	
	per cent	*pounds*	*pH*			*gm.*
1 A	25	0	6.9	7	8	0.95
2 A	25	50	6.5	18	12	0.99
3 A	25	250	6.8	31	43	1.04
4 A	25	500	6.9	60	76	0.97
5 A	25	1,000	7.2	61	67	0.92
6 A	25	3,000	7.0	70	70	0.97
7 A	25	5,000	7.3	47	40	0.92
1 B	50	0	6.7	4	20	1.12
2 B	50	50	6.9	14	19	1.11
3 B	50	250	6.9	40	27	1.15
4 B	50	500	7.1	60	55	0.95
5 B	50	1,000	6.7	60	60	1.01
6 B	50	3,000	7.0	98	85	0.97
7 B	50	5,000	7.0	94	83	1.11
1 C	75	0	6.5	7	6	1.23
2 C	75	50	6.6	12	16	1.12
3 C	75	250	6.5	55	57	1.18
4 C	75	500	7.1	122	†	1.13
5 C	75	1,000	7.0	88	89	1.01
6 C	75	3,000	7.2	115	92	0.97
7 C	75	5,000	7.0	106	91	1.09
1 D	100	0	6.5	9	11	1.34
2 D	100	50	6.6	8	20	1.29
3 D	100	250	6.4	60	59	1.34
4 D	100	500	7.0	151	103	1.43
5 D	100	1,000	7.0	132	124	1.25
6 D	100	3,000	7.3	108	136	1.22
7 D	100	5,000	7.0	142	126	1.25

* All pots received a general fertilizer application of:

	pounds per acre
Magnesium sulfate	15
Ferrous sulfate	10
Potassium hydroxide	61
Phosphoric acid	108

† Pot broken, no results obtained.

indicated in table 4 and was maintained at four different degrees of saturation. The results obtained agree fairly well with those obtained in experiment 1, as maximum nodulation was not obtained with applications of limestone under 500 pounds per acre and larger applications did not cause increased nodulation. Since nodulation was extremely limited in the absence of calcium, it may be concluded that calcium is essential for good nodulation. It was noted that the root development of plants having scant nodulation was poor, while top growth was fair. The nature of the relation between poor root development, poor nodulation, and fair top growth is not clear and therefore will not be discussed at this time.

TABLE 5

Effect of increasing applications of sodium nitrate upon nodulation

POT NUMBER	SATURATION OF SUBSTRATUM	SODIUM NITRATE APPLIED PER ACRE*	REACTION OF SUBSTRATUM AFTER 2 WEEKS' GROWTH	NUMBER OF NODULES PER 10 PLANTS	
				First	Second
	per cent	*pounds*	*pH*		
1	75	0	6.8	49	41
2	75	50	6.9	72	48
3	75	250	6.8	45	61
4	75	500	7.1	8	12
5	75	1,000	7.2	0	0
6	75	3,000	7.0	0	0

* All pots received a general fertilizer application of:

	pounds per acre
Magnesium sulfate	15
Ferrous sulfate	10
Potassium hydroxide	61
Phosphoric acid	108
Calcium carbonate	500

EXPERIMENT 5. EFFECT OF NITROGEN UPON NODULATION

While a study of the effect of nitrogen upon nodulation is somewhat different from the other studies reported in this paper, as atmospheric nitrogen is always potentially available to inoculated legumes, the study has been made to round out the work. The general outline of the nitrogen work is similar to the outlines used in the work upon the other elements. The substratum used was washed sand which was fertilized as indicated in table 5. Only one degree of saturation was used however. The results obtained indicate that small applications of nitrogen increase nodulation to a slight degree, but that fixed nitrogen is not essential for good nodulation and that high applications inhibit the infection of the host.

CONCLUSIONS

1. Elements essential for plant growth do not directly affect the infection and nodulation of legumes.
2. A high degree of saturation favors nodulation.

REFERENCES

(1) American Association of Official Agricultural Chemists 1921 Official and Tentative Methods of Analysis. Amer. Assoc. Off., Agr. Chem., Washington, D. C.

(2) FELLERS, C. R. 1918 The effect of inoculation, fertilizer treatment and certain minerals on the yield, composition and nodule formation of soybeans. *In* Soil Sci., v. 6, no. 2, p. 81–129.

(3) FLETCHER, C. C., AND BRYAN, H. 1912 Modification of the method of mechanical soil analysis. U. S. Dept. Agr. Bur. Soils Bul. 84.

(4) GILLESPIE, L. J. 1920 Colorimetric determination of hydrogen-ion concentration without buffer mixtures, with especial reference to soils. *In* Soil Sci., v. 9, no. 2, p. 115–136.

(5) HEINZE, B. 1910 Bodenbakteriologische Untersuchungen. *In* Landw. Jahrb., v. 39, no. 3, p. 314–343, *ref. in* Exp. Sta. Rec., v. 24, p. 326.

(6) PRUCHA, M. J. 1915 Physiological studies of *Bacillus radicicola* of Canada field pea. N. Y. (Cornell) Agr. Exp. Sta. Mem. 5.

(7) WILSON, J. K. 1917 Physiological studies of *Bacillus radicicola* of soy bean (*Soja max* Piper) and of factors influencing nodule production. N. Y. (Cornell) Agr. Exp. Sta. Bul. 386.

A NOTE ON THE NODULATION OF SOY BEANS[1]

ALFRED T. PERKINS[2]

New Jersey Argricultural Experiment Stations

Received for publication January 15, 1924

In the preceding paper (1) the conclusion was drawn that elements essential for plant growth do not directly affect the infection and subsequent nodulation of leguminous plants. In reaching this conclusion consideration was given to the fact that maximum nodulation was obtained in the absence of phosphorus and potassium. In the present paper a report is made of work carried out to determine possible reasons why essential elements favor nodulation under agricultural conditions and often tend to limit it under the conditions of these experiments. Consideration has been given to calcium as well as potassium and phosphorus.

METHODS

The methods followed were those outlined in the preceding paper and will be described here briefly only. A uniform plant stand was obtained in a series of pots filled with washed, fertilized quartz sand.—The crop grown was *Virginia* soy beans. Harvests and nodular counts were made four weeks after the seeds had germinated. Each pot held three pounds of sand which was maintained 75 per cent saturated, unless otherwise stated, by daily waterings with distilled water.

EXPERIMENT 1. EFFECT OF PHOSPHATE AND OSMOTIC PRESSURE UPON NODULATION

In an attempt to determine why acid phosphate inhibits nodulation, comparisons were made of the effect upon nodulation of increasing applications of acid and rock phosphate. Studies were also made of the effect upon nodulation of increasing osmotic pressures as governed by increasing fertilizer applications and amount of water in the substratum. The possible effect of acidity induced by acid phosphate has been considered.

[1] Paper No. 162 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology.

Part of thesis submitted to the faculty of Rutgers College in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] The author takes pleasure in expressing his gratitude to Dr. Lipman for general guidance in carrying out this work and to Prof. A. W. Blair, Dr. J. W. Shive, and Dr. S. A. Waksman for many helpful suggestions.

TABLE 1

Effect of increasing applications of acid and rock phosphate upon the nodulation of Virginia soy beans

SATURATION OF SUBTRACTUM	PHOSPHATE FERTILIZER APPLIED PER ACRE	ACID PHOSPHATE SERIES				ROCK PHOSPHATE SERIES			
		Reaction after 2 weeks growth	Nodules per 10 plants, average of 2 pots	Weight of air dried crop	Lowering of freezing point	Reaction after 2 weeks growth	Nodules per 10 plants, average of 2 pots	Weight of air dried crop	Lowering of freezing point
per cent	*lbs.*	*pH*		*gm.*	*°C.*	*pH*		*gm.*	*°C.*
25	0	6.4	50	1.59	0.03	6.5	53	1.56	0.03
25	50	6.4	78	1.33	0.03	6.6	65	1.55	0.03
25	250	6.4	63	1.55	0.04	6.5	76	1.60	0.03
25	500	6.3	24	1.45	0.05	6.5	78	1.60	0.03
25	1000	6.4	27	1.49	0.06	6.4	64	1.58	0.03
25	2000	6.4	40	1.24	0.16	6.4	64	1.62	0.03
25	3000	6.4	7	0.86	0.20	6.3	63	1.63	0.03
25	5000	6.3	0	0.57	0.20	6.2	64	1.65	0.04
50	0	6.4	120	1.74	0.01	6.4	108	1.71	0.02
50	50	6 5	115	1.67	0.01	6.5	109	1.68	0.02
50	250	6.4	110	1.45	0.02	6.5	99	1.82	0.02
50	500	6.4	96	1.54	0.02	6.5	108	1.62	0.02
50	1000	6.3	69	1.53	0.03	6.4	93	1.68	0.02
50	2000	6.4	48	1.36	0.07	6.3	102	1.73	0.02
50	3000	6.3	14	0.94	0.08	6.1	100	1.62	0.02
50	5000	6.4	0	0.70	0.12	6.3	105	1.72	0.02
75	0	6.4	123	2.09	0.01	6.4	122	2.25	0.01
75	50	6.5	118	2.07	0.00	6.5	97	2.08	0.01
75	250	6.4	120	1.81	0.01	6.5	99	2.28	0.01
75	500	6.4	100	2.03	0.02	6.5	90	2.28	0.01
75	1000	6.3	75	2.16	0.02	6.4	101	2.30	0.01
75	2000	6.4	40	1.51	0.05	6.3	94	2.17	0.01
75	3000	6.3	24	1.12	0.06	6.3	97	2.19	0.01
75	5000	6.3	3	1.02	0.09	6.2	103	2.22	0.01
100	0	6.2	87	1.78	0.01	6.3	93	2.18	0.01
100	50	6.5	75	1.99	0.00	6.5	82	1.83	0.01
100	250	6.3	94	1.88	0.01	6.4	99	1.96	0.01
100	500	6.4	85	1.97	0.01	6.5	99	1.82	0.01
100	1000	6.3	84	2.18	0.02	6.4	86	1.96	0.01
100	2000	6.4	41	1.97	0.03	6.2	92	2.00	0.01
100	3000	6.3	0	1.02	0.07	6.1	82	1.97	0.01
100	5000	6.3	0	0.82	0.08	6.2	87	1.88	0.01

All pots received a general fertilizer application of:

	lbs. per acre
Magnesium sulfate	15
Ferrous sulfate	10
Calcium carbonate	500
Potassium hydroxide	61

The data in table 1 show that under the conditions of the experiment rock phosphate had no appreciable effect upon the nodulation of soy beans. Practically the same degree of nodulation was obtained when an application of rock phosphate was made at the rate of five thousand pounds per acre, as when no phosphate was present in the substratum; while an application of one thousand pounds of acid phosphate materially reduced nodulation. In view of these facts it is evident that the toxicity of acid phosphate to nodulation is in some way associated with its solubility.

This toxicity might be due to an increased acidity, an increased osmotic pressure, or some physiological effect upon the host, infecting bacteria, or the symbiotic relationship.

TABLE 2

Effect of osmotic pressure upon nodulation

POT NUMBER	FERTILIZER APPLICATION*	SATURATION OF SUBTRATUM	LOWERING OF FREEZING POINT	NODULES PER 10 PLANTS	
				Pot a	Pot b
		per cent	°C.		
1	Normal	25	0.05	10	15
2	Normal	50	0.02	21	33
3	Normal	75	0.02	28	36
4	Normal	100	0.01	39	32
5	Normal	25	0.05	11	13
6	Twice normal	50	0.05	27	31
7	Three times normal	75	0.05	34	30
8	Four times normal	100	0.05	49	35

*A normal fertilizer application was:

	lbs. per acre
Magnesium sulfate	15
Ferrous sulfate	10
Calcium carbonate	500
Potassium hydroxide	61
Acid phosphate	500

That the acidity is not the factor which limits nodulation is evidenced by the fact that active acidity as indicated by pH values remained practically unchanged even after the largest addition of acid phosphate.

That the osmotic pressure is not the limiting factor is shown by the data in tables 1 and 2. In table 1 it is seen that although nodulation varies indirectly with osmotic pressure, whether the osmotic pressure be varied by altering fertilizer application or water content of the substratum, this variation is not constant. When the substratum is 25 per cent saturated and fertilizer applications have reduced the freezing point 0.20°C., nodulation is inhibited; but when the substratum is 100 per cent saturated nodulation is limited by a lowering of the freezing point by only 0.07 degrees. With the above data in mind the work as outlined in table 2 was carried out. Here in one case the

salt application was maintained constant while the degree of saturation was increased with a resulting decrease in osmotic pressure, and in the other case osmotic pressure was maintained constant by increasing fertilizer applications as the degree of saturation was increased. The results obtained clearly indicate that there is little relation between osmotic pressure (in the degrees obtained in this experiment) and nodulation. If there is any relation it is such that the relation between moisture content of the substratum and nodulation completely hides it.

Considering table 2, the fact that the relation between fertilizer application and osmotic pressure was so easily obtained is attributed to the fact that the substratum was washed sand which has a very small power of adsorption.

In view of these facts and the fact that nodulation tends to decrease as plant growth decreases, it may be assumed that acid phosphate limits nodulation by affecting some physiological activity of the plant.

Studies of the effect of acid phosphate upon the toxicity of certain minerals to nodulation will be reported under experiment 3.

EXPERIMENT 2. THE EFFECT OF LIME UPON NODULATION

In the preceding paper (1) the only element reported as increasing nodulation was calcium. Theoretical considerations show that calcium might aid nodulation by:

1. Eliminating the effect of acid radicals
2. Counteracting the effect of non-acid toxic ions
3. Entering into the mechanism of infection or nitrogen fixation
4. Being the element which would first limit the growth of soy bean seedlings

That under the conditions of these experiments calcium does not aid nodulation by neutralizing the effects of acid radicals is shown by the data in table 3. Here the acidity was completely neutralized by the addition of a non calcic base and in spite of this neutralization increasing applications of lime increased nodulation in approximately the same degree as when the non calcic base had not been added. It has also been noted that good nodulation may take place at pH values lower than those at which nodulation was limited by the lack of lime.

That calcium can neutralize the toxic effect of certain mineral substances is shown by the results give in table 4. The toxic substance to be counteracted in this case was acid phosphate a substance which readily reacts with lime. The acid phosphate was applied at the rate of five thousand pounds per acre, an amount which will completely inhibit nodulation. The control series which received an application of acid phosphate at the rate of 135 pounds per acre shows the effect of increasing applications of lime in the absence of a toxic phosphate application. The results obtained indicate that when the pots are seeded immediately after being prepared, increasing applications of lime

have little beneficial effect upon nodulation; but that when time is allowed for the phosphate and lime to react applications of lime increase nodulation.

Some consideration as to the effect of lime upon the toxicity to nodulation induced by applications of other minerals is given under experiment 3.

TABLE 3

Effect of increasing applications of lime upon nodulation in a substratum neutralized by a non-calcic base

POT NUMBER	CALCIUM CARBONATE APPLIED PER ACRE	NEUTRALIZATION OF SOIL	REACTION AFTER 2 WEEKS GROWTH	NUMBER NODULES PER 10 PLANTS, AVERAGE 2 POTS
	lbs.		*pH*	
1	0	0.07 gm. NaOH per pot	7.1	2
2	50		7.2	16
3	250		7.1	20
4	500		7.3	37
5	1000		7.2	43
6	3000		7.2	49
A1	0	0.25 gm. Na_2CO_3 per pot	7.0	8
A2	50		6.9	11
A3	250		7.1	27
A4	500		7.2	42
A5	1000		7.2	48
A6	3000		7.3	51
B1	0	Not neutralized	5.6	15
B2	50		5.8	18
B3	250		6.0	46
B4	500		6.4	55
B5	1000		6.6	67
B6	3000		6.7	54

The substratum in all pots was maintained 75 per cent saturated.
Substratum was washed quartz sand fertilized with:

	lbs. per acre
Magnesium sulfate	15
Ferrous sulfate	10
Potassium hydroxide	61
Acid phosphate	135

That calcium either enters into the mechanism of infection and nitrogen fixation or is the element which limits the growth of the seedlings seems probable since the poorest developed plants in the lime series were those that had received little or no lime. The plants in pot 27 (table 4) were of much better color etc., than the plants in pot 21 even though air-dry weights indicate that both sets of plants were equally developed.

TABLE 4

Effect of increasing applications of calcium carbonate upon nodulation in the presence of an excess of acid phosphate

POT NUMBER	CALCIUM CARBONATE APPLIED PER ACRE	REACTION AFTER 2 WEEKS GROWTH	NUMBER NODULES PER 10 PLANTS, AVERAGE 2 POTS	WEIGHT OF AIR DRIED CROP
	lbs.	*pH*		*gm.*
1	0	5.6	15	....
2	50	5.8	18	....
3	250	6.0	46	....
4	500	6.4	55	....
5	1000	6.6	67	....
6	3000	6.7	54	....
11	0	5.5	0	0.00
12	50	5.8	0	0.00
13	250	5.7	0	0.00
14	500	5.9	0	scant
15	1000	5.9	0	scant
16	3000	6.4	0	scant
17	5000	6.4	8	scant
21	0	5.6	2	1.06
23	250	5.7	20	0.95
24	500	5.8	25	0.91
25	1000	5.9	31	1.02
26	3000	6.0	52	0.98
27	5000	6.5	77	1.06

Pots numbered 1 to 6 received 135 pounds of acid phosphate per acre.

Pots numbered 11 to 17 received 5000 pounds of acid phosphate per acre and were planted immediately after application of fertilizers.

Pots numbered 21 to 27 received 5000 pounds of acid phosphate per acre and were planted three weeks after application of fertilizers.

All pots received a general fertilizer application of:

	lbs. per acre
Magnesium sulfate	15
Ferrous sulfate	10
Potassium hydroxide	61

EXPERIMENT 3. EFFECT OF INCREASING APPLICATIONS OF ESSENTIAL ELEMENTS UPON TOXICITY TO NODULATION INDUCED BY NON-ESSENTIAL ELEMENTS

From the data presented in this and the preceding paper no explanation can be made for the fact that various investigators have found that applications of essential elements benefit nodulation. Since the manner in which the elements studied affect the nodulation of young plants is at best uncertain it is possible that when they do favor nodulation they do so by counteracting something that is toxic to nodulation. In view of this consideration the applications of iron, aluminum, copper and manganese toxic to nodulation were determined.

TABLE 5

Effect of increasing applications of mineral fertilizers upon toxicity to nodulation induced by certain minerals

TOXIC MINERAL APPLIED	FERTILIZER APPLICATION PER ACRE	NUMBER NODULES PER 10 PLANTS—AVERAGE FOR 2 POTS		
		Acid phosphate series	Potassium chloride series	Calcium carbonate series
	lbs.			
None	0	92	40	10
	50	86	33	17
	250	79	39	30
	500	70	28	35
	1000	29	24	38
	3000	11	6	40
$FeSO_4$	0	3	25	0
	50	17	129	8
	250	27	21	10
	500	20	12	11
	1000	4	4	12
	3000	1	0	70
$AlSO_4$	0	10	21	0
	50	5	20	3
	250	22	17	3
	500	6	22	7
	1000	0	7	6
	3000	0	0	19
$CuSO_4$	0	0		
	50	0		
	250	0		
	500	0		
	1000	0		
	3000	0		
$MnSO_4$	0	9		
	50	21		
	250	42		
	500	33		
	1000	21		
	3000	0		

All pots received a general fertilizer application of 15 pounds of magnesium sulfate per acre and 10 pounds ferrous sulfate per acre.

The acid phosphate series also received 61 pounds of potassium hydroxide and 500 pounds of calcium carbonate per acre.

The calcium carbonate series also received 61 pounds of potassium hydroxide and 135 pounds of acid phosphate per acre.

The potassium chloride pots also received 500 pounds of calcium carbonate and 135 pounds of acid phosphate per acre.

The substratum was washed sand maintained 75 per cent saturated.

Iron was chosen because it is a mineral found in most soils and affects plants under acid conditions. Aluminum was chosen for the same reasons. Copper was selected because it is an element toxic to plant activities even though rarely present in the soil in large amounts. Manganese was selected because past studies have shown that small applications of it affect nodulation to a large extent. All of these elements were applied as the sulfate in amounts which hot house tests demonstrated to be toxic to nodulation. The amounts used were:

0.3418 gms. $FeSO_4 \cdot 7H_2O$ per pot
0.6836 gms. $AlSO_4 \cdot 18H_2O$ per pot
0.1709 gms. $CuSO_4 \cdot 5H_2O$ per pot
0.1709 gms. $MnSO_4 \cdot 4H_2O$ per pot

The results obtained from increasing applications of mineral fertilizers are given in table 5.

These results indicate that acid phosphate reduces the toxicity to nodulation caused by an excess of iron, aluminum, or manganese; that potassium chloride may reduce the toxicity to nodulation resulting from an excess of iron or alumium; and that calcium carbonate may reduce the toxicity of an excess of acid phosphate (see table 4). Applications of calcium probably reduce the toxicity of iron and aluminum; but this is not definite since when no calcium was present nodulation was limited by the lack of lime as well as the toxicity of the mineral elements.

GENERAL DISCUSSION AND CONCLUSIONS

From the literature it is evident that under general farming conditions applications of phosphorus and potassium and calcium increase nodulation. The manner in which these elements affect nodulation is at best problematical. From the data presented it is seen that all three elements under consideration may increase nodulation by counteracting factors limiting this process. Calcium in addition to this power seems either to enter into the mechanism of infection and subsequent fixation of nitrogen or to be the element which would first become the limiting factor in the growth of the seedlings. In consideration of the above discussion and data presented the following conclusions have been drawn.

1. When phosphorus and potassium increase nodulation they may do so by counteracting some toxic factor in the soil.

2. When calcium increases nodulation it may do so by counteracting some toxic factor in the soil, by entering directly into either the process of infection or nitrogen fixation, or as a result of being the first element to limit the growth of the seedlings by its absence.

3. Under the conditions of these experiments when the elements under consideration affect nodulation they may possibly do so by disturbing the physiological activities of the plants.

REFERENCE

(1) PERKINS, A. T. 1924. The effect of several mineral fertilizers upon the nodulation of Virginia soy beans. *In* Soil Sci., v. 17, p. 439–447.

THE VALUE OF SOIL ANALYSIS WHEN LIMITED TO AN INTENSIVE SINGLE CROPPING SYSTEM

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Received for publication January 9, 1924

In studying the interrelations of soils and plants, soil analysis as an indication of fertilizer requirements or as a measure of plant food availability appears to conflict with certain modern views. Experimental tendencies are now directed toward a more complete knowledge of the inherent physiological properties of plants as influenced by variations in the plant food balance. This is due to the failure to definitely associate the analysis of the soil with variations in plant growth and adaptation. There are undoubtedly thoroughy sound principles on which to base such tendencies. A knowledge of the total mineral nutrient content of the soil or that which is soluble in strong acids is practically valueless for immediate crops without some knowledge of the availability. It has some value as a measure of reserve plant food, marked deficiencies or abundance being usually indicated, but this is of minor importance as compared to the forms in which these nutrients are present. The possible combinations in the soil are legion and in order to detect changes in soil composition which result from fertilizer applications, which amounts are sufficient to stimulate plant growth, it is necessary to resort to the use of water or dilute acids. Determination of the effect of a fertilizer application is not within the range of the accuracy of concentrated solvents.

In Hawaiian soils, the high colloidal content of which imparts strong fixing properties, little success has thus far attended the use of water extracts. This is especially true with phosphates. Dilute acids, therefore, appear to be the only possible recourse on such soil types in which low reserve plant food content is rarely noted. Even here fixation in the presence of the solvent is a notable factor.

Sugar cane appears to make heavy demands upon the mineral nutrients at certain definite stages of growth. It is evident that a measure of available plant food is of greater value than a water extract which is too greatly influenced by the high fixing power of our soils. With our crop, adequate supplies of available plant food and the rate at which the replenishment of the soil solution is possible, are the important factors rather than the actual concentration of the soil solution at any period. The solvent, in order to be of value in soil analysis, should show some definite relation between the

soil and the food requirement of the crop. The value of any method, therefore, depends on the accuracy with which this analysis can be accomplished. On this basis we have a point in favor of dilute acids.

Lack of thoroughly sound theoretical principles on which to base the extraction of the soil with dilute acids must be admitted. It is true that the solvent properties of dilute acids for definite phosphate or potash compounds can be accurately determined, but when applied to soil conditions other factors will more or less influence solubility, thus limiting the general application of this property. The only possible value of dilute acids lies in the empirical establishment of a working agreement between the extraction of mineral nutrients and response of a soil type to fertilization. In other words it is essential to corroborate the chemical analysis with numerous field experiments and a knowledge of the feeding power and other peculiarities of the crop,

In the Hawaiian Islands, approximately 225,000 acres are devoted to the culture of sugar cane. The conditions so far as this crop is concerned are as follows. We are dealing with one crop and are therefore concerned only with such variation in feeding power as might exist between different varieties. While we have quite a wide variation in soil types the lands cultivated to sugar cane involve only the lowland sections usually skirting the shore line of the islands. Cropping is continuous and fallowing or rotation rarely practiced, so the soil is never at rest. In such a continuous system of cropping there is a constant drain on the plant nutrients and less opportunity for the natural agents such as aeration and fallowing to increase the availability of plant food in the soil.

A survey of crop reports shows a wide variation in yields per acre in the different sections of the Islands or even on the same plantation. This variation is due mainly to environment, temperature, exposure and moisture supply. Variation in mineral nutrients present in the soil is only a minor factor in comparison. On the other hand the extensive field experiments, conducted by this experiment station, have noted definite areas in which phosphate and potash deficiencies are a limiting factor. Composite soil samples have been taken from a number of these experiments submitted to various methods of analysis and the results compared with the known history of the soil. The comparative value of these methods is strikingly illustrated by the data thus obtained.

PHOSPHATES

Details covering methods of analysis are obviously outside the scope of this article. Suffice it to say that total P_2O_5 was determined by fusion with sodium carbonate; extraction with concentrated HNO_3 by digesting 2 gm. soil with 30 cc. acid for twenty hours on the steam bath; extraction with concentrated HCl by the so called agricultural method; extraction with 1 per cent citric acid by shaking 100 gm. soil with 1 liter solvent for six hours;

extraction with 0.2 *N* nitric acid by digesting 120 gm. of soil with 1200 cc. acid for five hours at 40°C. The results are given in table 1.

TABLE 1

Analyses of soils from phosphate experiments

SOIL NUMBER	TOTAL	BY CONCENTRATED HNO_3	BY CONCENTRATED HCl	BY 1 PER CENT CITRIC	BY 0.2 N HNO_3
		Per cent of P_2O_5 in soils giving no response			
3578	0.46	0.34	0.30	0.0030	0.00051
405	0.42	0.36	0.33	0.0035	0.00121
844	0.55	0.34	0.22	0.0228	0.00410
872	0.60	0.26	0.20	0.0726	0.02480
239	1.06	1.04	0.94	0.0441	0.07920
3	1.13	0.70	0.50	0.3190	0.16280
538	0.47	0.35	0.38	0.0034	0.00048
318	0.42	0.35	0.25	0.1283	0.00950
418	0.23	0.16	0.12	0.0030	0.00040
7103	0.57	0.30	0.24	0.0164	0.00510
5493	0.95	0.66	0.18	0.0049	0.00093
7658	1.06	0.66	0.41	0.0058	0.00080
10781	1.66	1.17	0.46	0.0176	0.00420
		Per cent of P_2O_5 in soils giving response			
3460	0.38	0.25	0.21	0.0014	0.00028
3985	0.46	0.21	0.24	0.0009	0.00026
996	0.24	0.16	0.11	0.0008	0.00015
998	0.57	0.46	0.45	0.0028	0.00034
999	0.56	0.43	0.38	0.0024	0.00037
444	0.28	0.13	0.16	0.0024	0.00060
750	0.25	0.16	0.15	0.0027	0.00060
621	0.21	0.13	0.06	0.0011	0.00038
7147	0.17	0.12	0.04	0.0009	0.00023

TABLE 2

Showing maximum, minimum and average P_2O_5 as measured by 1 per cent citric and 0.2 N nitric acids

	1 PER CENT CITRIC	0.2 N NITRIC
	Per cent of P_2O_5 in soils giving no response	
Average	0.0493	0.02260
Maximum	0.3190	0.16280
Munimum	0.0030	0.00040
	Per cent of P_2O_5 in soils giving response	
Average	0.0017	0.00034
Maximum	0.0028	0.00060
Minimum	0.0008	0.00015

The results obtained by fusion and solubility in strong nitric and hydrochloric acids warrant little comment. Few Hawaiian soils are lacking in reserve phosphate. On the other hand it will be noted that there is a marked correlation between the phosphate content as measured by 0.2 *N* nitric acid and 1 per cent citric and response of sugar cane to phosphate manuring on our island soils. These figures are further presented in condensed form in table 2.

In view of the above, certain solvent properties of these acids were studied in order to arrive at a better comparison of their values. In brief these results showed a surprising absorption of P_2O_5 by the soil in contact with 0.2 *N* nitric acid which was true to a far less extent of 1 per cent citric acid. This lesser degree of fixation in the presence of solvent, a greater solvent power, absence of the effect of amount of acid neutralized during extraction and the fact that the P_2O_5 soluble in 1 per cent citric acid is completely removed in one extraction indicated this solvent to be better adapted to our requirements. In this series of soil samples taken from twenty-three field experiments located on fifteen different plantations including four islands, all soils containing less than 0.003 per cent P_2O_5 soluble in 1 per cent citric acid responded to phosphates. This solvent therefore merits consideration as a measure of available phosphoric acid in Hawaiian soils cropped to sugar cane.

POTASH

Applying these same methods of analysis, with the exception of concentrated nitric acid which was omitted, and total K_2O in which the soil was decomposed by hydroflouric, nitric and sulfuric acids, to composite samples of soil taken from potash field experiments the results which were obtained are given in table 3.

Here, again, we note a high reserve potash content usually present and little or no relation between total potash soluble in concentrated HCl and potash fertility. On the other hand there will be noted a decided relation between K_2O as determined by 1 per cent citric acid and response of the soil to potash fertilization. For the soils in which field experiments showed a deficiency of available potash, the determinations varied from 0.009 to 0.023 per cent, with an average of 0.014 per cent. Those soils which appear to be amply supplied with available potash, were shown to contain 0.031 to 0.082 per cent K_2O soluble in 1 per cent citric acid with an average of 0.054 per cent. In other words, no soil containing more than 0.023 per cent K_2O gave profitable returns from potash manuring. Analysis of extracts made with 0.2 *N* nitric acid gave results of little or no value.

These soil samples were taken from fourteen field experiments located on thirteen different plantations on four islands and indicate the value which may be attached to the results obtained by this method.

TABLE 3

Analyses of soils from potash experiments

SOIL NUMBER	TOTAL	BY CONCENTRATED HCl	BY 1 PER CENT CITRIC	BY 0.2 N HNO_3
Per cent K_2O in soils giving no response				
239	2.95	2.14	0.054	0.051
3	1.61	0.43	0.065	0.122
7502	1.04	0.52	0.050	0.070
7225	0.38	0.32	0.055	0.038
405	1.05	0.49	0.049	0.050
710	1.10	0.52	0.082	0.223
999	1.12	0.38	0.031	0.063
Per cent K_2O in soils giving response				
7658	0.66	0.31	0.017	0.042
10970	0.54	0.33	0.012	0.014
11014	0.65	0.21	0.011	0.012
7692	0.95	0.35	0.023	0.045
10703	0.79	0.38	0.009	0.025
3985	0.67	0.40	0.015	0.034
11462	0.46	0.15	0.014	0.092

DISCUSSION

It is not suggested that there is any evidence of the existance of two definite groups of phosphate or potash compounds, available and unavailable but, rather that they may be present in the soil in different degrees of disintegration and therefore, availability. In such a complex material as soil, it is not possible to select a solvent which will dissolve any definite phosphate or potash compound exclusive of another in entirety. Results obtained on our island soils do, however, show a higher calcium phosphate content in the coral impregnated areas with iron and aluminum phosphates predominating in other types, even though the coral soils are very high in iron and aluminum.

Again the general adaptation of this method is not advocated. Local conditions are admittedly specific. The influence of variation in soil types and feeding power of plants is known to be a factor. This point is clearly indicated by a comparison with the work of Dyer (2) who considered a soil deficient in plant food if it contained 0.01 per cent P_2O_5 or 0.005 per cent K_2O; Hall and Plymen (5) who suggested 0.02 per cent for P_2O_5; Wood and Berry (10) who suggested 0.02 per cent for P_2O_5 and 0.01 per cent for K_2O; Tempany (9) who considered 0.005 per cent low and 0.01 per cent high for P_2O_5, and Dunlop (1) who advised manuring for soils containing less than 0.005 per cent P_2O_5 and 0.006 per cent K_2O.

Also, it may not be amiss to compare the figures obtained with 0.2 *N* nitric acid in which no soil containing more than 0.0006 per cent P_2O_5 responded to phosphate manuring with those of Snyder (7, 8) where all soils containing

0.0025 to 0.0083 per cent P_2O_5 gave response; the Texas Station (3) where a content of 0.002 per cent of P_2O_5 is considered deficient and the Wisconsin Station (6) where 0.015 per cent is considered low. In potash experiments, Snyder (7, 8) found 0.015 per cent K_2O in a soil giving response, Fraps (4) found all soils containing less than 0.005 per cent P_2O_5, 87 per cent deficient and those containing 0.005 to 0.015 per cent P_2O_5, 55 per cent deficient.

On the basis of the above investigation which will be published in detail in bulletin form, 1 per cent citric acid is being extensively applied to Hawaiian soils as a guide to fertilizer policy on the sugar plantations. It is further suggested that 1 per cent citric acid may be of considerable value under similar limited conditions. It should be mentioned however, that interpretation is not based entirely on chemical analysis alone. There has been noted a definite relation between forms of silica and lime present in Hawaiian soils as well as the soil reaction and availability of P_2O_5. Also that response to phosphate manuring is typical of upland areas and rarely obtained on lowland soils. The availability of potash appears to be influenced by the physical composition of the soil, lime content and reaction with an additional association of low availability in the districts of heavy rainfall. Consideration must therefore be given to the above factors and a more or less intimate knowledge of the properties and past performance of the soil type. The high feeding power of sugar cane for phosphoric acid is also considered. Recommendations from the above data are therefore suggested only as a matter of policy and not "laid down" as an infallible rule as variations are admitted.

REFERENCES

(1) DUNLOP, W. R. 1915. Manurial experiments with sugar cane in British Guiana. *In* West Ind. Bul., v. 15, p. 228.

(2) DYER, BERNARD. 1894. On the analytical determination of probably available mineral plant food in soils. *In* Jour. Chem. Soc. (Trans.), v. 65, p. 115.

(3) FRAPS, G. S. 1910. Active phosphoric acid and its relation to the needs of the soil for phosphoric acid in pot experiments. Texas Agr. Exp. Sta. Bul. 126.

(4) FRAPS, G. S. 1912. The active potash of the soil and its relation to pot experiments. Texas Agr. Exp. Sta. Bul. 145.

(5) HALL, A. D., AND PLYMEN, F. J. 1902. The determination of available plant food in soils by use of weak acid solvents. *In* Jour. Chem. Soc. (Trans.), v. 81, p. 117.

(6) STODDART, C. W. 1910. Phosphate availability in its relation to soil acidity. Wis. Agr. Exp. Sta. Res. Bul. 2.

(7) SNYDER, H. 1899. The available plant food of soils. Minn. Agr. Exp. Sta. Bul. 65.

(8) SNYDER, H. 1908. A comparison of chemical methods and field tests for determining the fertilizer requirements of soils. Minn. Agr. Exp. Sta. Bul. 102.

(9) TEMPANY, H. A. 1915. The soils of Antigua. *In* West Ind. Bul., v. 15, p. 69.

(10) WOOD, T. B., AND BERRY, R. A. 1905. Soil analysis as a guide to manurial treatment of poor pastures. *In* Jour. Agr. Sci., v. 1, p. 114.

THE INFLUENCE OF SILICA, LIME AND SOIL REACTION UPON THE AVAILABILITY OF PHOSPHATES IN HIGHLY FERRUGINOUS SOILS

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Received for publication January 9, 1924

The sugar lands of Hawaii are practically all located at the lower elevations skirting the shore line of the islands. In some cases the increase in altitude from the shore line is quite rapid but little cane culture is practiced above an elevation of 1500 feet. Extensive field experiments conducted by this experiment station have shown response to phosphate fertilization to be more or less typical of upland areas. On the other hand response is rarely noted on lowland soils. These observations suggested some inherent properties which would account for this apparent variation in phosphate availability. A chemical examination of thirty-nine soil samples collected from field experiments located on widely varying soil types on the four major islands, Hawaii, Maui, Kauai and Oahu indicated silica, lime and soil acidity to be the principal factors involved. Of the thirty-nine samples, fourteen gave response and twenty-five no response to phosphate fertilization.

RELATION OF SILICA TO AVAILABILITY

Pfeffer (6) classifies silica among the non-essential elements yet points out that in nature where competition is severe a non-essential element may be of decisive importance. In the ash of grasses, silica may form 50–80 per cent of the whole. This is a distinguishing feature of the Gramminae of which class sugar cane is a member. Maxwell (3) found 50–60 per cent silica in the ash of Hawaiian canes. At Rothamstead (1), sodium silicate has been applied in certain of their experiments over a long period and has caused a response similar to that noted on the phosphate plots. Schollenberger (7) has recently found a greater phosphate content in the crop grown with lime and silicate than where lime alone was used, the soil being the only source of phosphate.

In Hawaiian soils there is almost universally present large amounts of soluble silica although the total silica is considered very low. In the analyses of these thirty-nine samples, total SiO_2 varied from 14 to 35 per cent on the water free soil but there was no relation between this and the availability of P_2O_5. In a classification of the lime compounds of soils, Shorey, Fry and

Hazen (8) have assumed that 4 per cent HCl acts as a solvent for easily decomposible calcium silicates. On this basis 4 per cent HCl was used as the principal solvent in this soil series. Calcium silicate soluble in 1 per cent citric was also determined. The results are given in table 1.

There is shown in table 1 a marked relation between the solubility of silica in the soils from these field experiments and response to phosphate fertiliza-

TABLE 1

Relative solubility of silica in 1 per cent citric acid and 4 per cent hydrochloride acid

SOLUBILITY OF SiO_2 IN SOILS GIVING RESPONSE				SOLUBILITY OF SiO_2 IN SOILS GIVING NO RESPONSE			
Island	Soil number	Extracted with 1 per cent citric	Extracted with 4 per cent HCl	Island	Soil number	Extracted with 1 per cent citric	Extracted with 4 per cent HCl
		per cent	*per cent*				
	364	0.016	0.04	Kauai	375	0.14	0.25
	398	0.019	0.03		378	0.09	0.23
	995	0.008	0.04		405	0.10	0.25
Kauai	996	0.025	0.11				
	998	0.075	0.34	Oahu	844	0.16	0.71
	999	0.072	0.30		872	0.29	0.81
	1000	0.019	0.06		239	0.19	0.87
					3	1.24	1.25
	444	0.090	0.27		538	0.18	0.27
Oahu	750	0.088	0.33		318	0.22	0.34
					418	0.26	0.32
	621	0.125	0.21				
	714	0.089	0.25	Maui	710	0.13	0.30
	715	0.110	0.25		711	0.12	0.30
Maui	716	0.112	0.25		712	0.14	0.30
	717	0.105	0.25		713	0.12	0.30
				Hawaii	549	0.11	0.95
					551	0.11	1.28
					553	0.10	1.46
					765	0.11	0.83
					766	0.11	1.20
					767	0.10	0.99
					768	0.14	1.29
					1078	0.17	1.97
					1079	0.08	0.77
					1080	0.10	1.68
					1081	0.13	1.51

tion. This indicates that a greater availability of P_2O_5 will accompany a greater availability of silica. As for the relative assimilation of P_2O_5 from these soils by the cane the following observations are of interest. Soil 3 contains the highest citric soluble silica and is one of the highest in silica soluble in 4 per cent HCl. McAllep and Bomonti (4) have determined the phosphate content of juice from cane grown on this soil and found it to be

the highest in P_2O_5 yet examined, namely 0.10 per cent. The soils from the Hilo-Hamakua coast district of Hawaii have rarely shown response to phosphates. This section is represented in table 1 by the ten soils from Hawaii. These are high in the available forms of silica and the juices have been found to be uniformly high in P_2O_5. On the other hand juices from cane grown on soils 444 and 750 are very low in P_2O_5, that is 0.01 to 0.015 per cent. This was only very slightly increased by phosphate fertilization at the rate of 180 pounds P_2O_5 per acre although the yield of cane was greatly increased. In other words the results do not indicate that the percentage of P_2O_5 in the juice will be greatly increased by phosphate applications to a soil low in phosphates but rather that a supply of available silica is a factor in the assimilation.

LIME AND SOIL ACIDITY

Frequent reference is to be noted in soil literature to the relation of lime and soil acidity to the availability of soil phosphates. It is now quite generally established that certain unproductive acid soils may be restored to normal by phosphate manuring as well as by liming. One example of such a soil has been noted here in Hawaii (2). Liming on an upland soil in the Haiku district on the Island of Maui failed to correct an apparent toxicity where phosphates produced large gains ranging from 80 to 500 per cent.

In determining the forms of lime present in these soils the procedure adopted by Shorey (8) involving the use of 2 per cent HCl as a solvent for calcium carbonate, calcium sulfate and so-called calcium-humus compounds and that of 4 per cent HCl for extracting additionally the easily decomposible silicates was used. The total lime was determined by fusion with Na_2CO_3. That soluble in water saturated with carbon dioxide was determined by shaking one part soil to five parts water for five hours in a shaking machine. Hydrogen-ion concentration was determined with the hydrogen electrode. The results are given in table 2 and calculated to the water-free basis.

The higher hydrogen-ion concentration in those soils giving response to phosphate fertilization is significant. The principal exceptions are the soils from the Island of Hawaii which are high in acidity yet do not respond to phosphates. These soils are a distinct type, highly hydrated and the acidity appears to be due to the presence of acid silicates developed from excessive rainfall and leaching of lime, magnesia, potash and soda which tend to maintain the alkalinity or neutrality of such compounds. The higher availability of phosphate in this soil type is probably associated with the high availability of silica and the high phosphate content. On the other soil types, no soil with a pH value above 6.3 showed any lack of available phosphate while with one exception all soils with a pH value of 6.3 or lower gave response.

A similar relation applies to lime and especially in regard to the relative solubility in water saturated with carbon dioxide. In general, those soils giving response to phosphates are lower in total lime present as carbonate

TABLE 2

Showing relation of hydrogen-ion concentration and lime to availability of P_2O_5

ISLAND	SOIL NUMBER	REACTION	TOTAL CaO	CaO SOLUTION 4 PER CENT HCl	CaO SOLUTION 2 PER CENT HCl	CaO SOLUBLE IN CARBONATED WATER
		pH	*per cent*	*per cent*	*per cent*	*p.p.m.*
			Soils giving no response			
Kauai	375	7.5	1.14	0.58	0.55	938
	378	6.6	1.29	0.79	0.27	503
	405	6.3	1.11	0.40	0.34	429
Oahu	844	6.6	1.43	0.87	0.74	448
	872	7.7	3.01	1.26	0.88	895
	239	8.1	6.90	6.18	4.21	2010
	3	8.2	2.66	1.55	1.16	1070
	538	7.7	1.23	0.26	0.24	352
	318	7.7	1.25	0.48	0.39	...
	418	7.3	1.02	0.34	0.30	....
Maui	710	6.8	1.02	0.33	0.30	363
	711	6.8	1.02	0.33	0.30	363
	712	6.8	1.02	0.33	0.30	363
	713	6.8	1.02	0.33	0.30	363
Hawaii	549	6.4	1.31	0.64	0.62	588
	551	6.2	1.25	0.51	0.49	450
	553	6.1	1.11	0.47	0.46	445
	765	5.1	1.04	0.45	0.11	175
	766	5.3	0.96	0.46	0.10	175
	767	5.3	0.92	0.44	0.06	175
	768	5.6	1.11	0.52	0.14	207
	1078	5.0	0.94	0.17	0.16	137
	1079	5.1	0.88	0.16	0.15	137
	1080	5.1	0.88	0.17	0.12	137
	1081	5.1	0.99	0.18	0.15	137
			Soils giving response			
Kauai	364	4.6	0.81	0.10	0.07	99
	398	4.8	0.87	0.12	0.10	127
	995	5.3	0.56	0.33	0.24	179
	996*	6.8	1.52	1.18	1.05	1165
	998†	6.5	0.86	0.61	0.43	468
	999†	6.3	0.71	0.48	0.39	424
	1000	5.2	0.42	0.15	0.10	100
Oahu	444	6.3	1.18	0.32	0.22	33
	750	5.8	0.88	0.15	0.22	23
Maui	621	5.9	0.88	0.16	0.14	25
	714	6.3	0.98	0.17	0.15	17

*This soil had received a heavy lime application.

†These soils had received an application of molasses ash which contains considerable potassium carbonate.

and sulfate as well as easily soluble silicates. These facts point strongly toward a definite influence which lime exerts over the availibility of phosphates in soils high in iron and aluminum. This is further indicated by the high P_2O_5 content of juice from cane grown on the high lime soils.

DISCUSSION

Our studies on Hawaiian soils have shown the large amounts of aluminum phosphate which are present and lesser amounts of iron and calcium phosphates in the order given. These studies further show that where an excess of lime is present, for example the coral interspersed areas, the percentage of phosphate combined with aluminum and iron is low and that the availability and assimilation by the cane is high, in spite of the fact that there is little consistent difference in the iron and aluminum content of the two types. On the other hand the analyses of upland soils show a lower lime content, higher acidity, lower availability and larger quantities of soluble or active aluminum.

The normal phosphates of iron and aluminum have been shown to give response on Hawaiian soils deficient in this form of plant food (5). This suggests the association of basic phosphates with the low availability of phosphates in island types.

The availability of phosphates in the virgin soils of these islands is notably increased by cultivation and other tillage practices. It is possible to explain this on the basis of a stimulation of the buffer action of $CaHCO_3$ through the introduction of carbon dioxide into the soil atmosphere by aeration. The carbon dioxide precipitates the elements which stand higher in the electromotive series and whose basic phosphates are less easily attacked by the agents of solution.

Again the subsoils of these islands are notably lower in available phosphates than the corresponding top soil. Here also we have a lower lime content, less aeration and higher acidity. There results from the above environment an excess of the phosphates of iron and aluminum both normal and hydrated as shown by our soil analyses.

The work of Walker (9) illustrates these principles. These investigators, in their examination of the phosphate content of the juice from a number of fields at Pioneer Plantation on the Island of Maui, found that the juices from cane grown in the lower elevations were richest in P_2O_5. Cane juice produced at an elevation of 500 feet contained slightly less P_2O_5 and at the highest elevations, the least P_2O_5. This plantation is so situated that there is a gradual slope up the mountain to an altitude of 1500 feet. Messrs. Stewart and Hansson, of this station, have recently completed a soil survey of this plantation. Their analyses have been separated as to altitude, averaged and are shown here:

Relations of altitude, soil reaction, and soil composition to P_2O_5 in cane juice

ALTITUDE	REACTION	CaO SOLUBLE IN CONCENTRATED HCl	CaO SOLUBLE IN 1 PER CENT CITRIC ACID	TOTAL P_2O_5 CONTENT	P_2O_5 SOLUBLE IN 1 PER CENT CITRIC ACID	SiO_2 SOLUBLE IN 1 PER CENT CITRIC ACID	P_2O_5 IN JUICE*
feet	*pH*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
100	7.9	3.23	0.39	0.37	0.0320	0.23	0.063
200	7.3	0.40	0.22	0.34	0.0064	0.17	0.024
300	7.2	0.46	0.20	0.27	0.0044	0.18	
400	6.7	0.33	0.17	0.32	0.0045	0.13	
500	6.6	0.28	0.16	0.32	0.0039	0.14	
700	6.2	0.31	0.15	0.26	0.0042	0.12	
800	6.0	0.22	0.11	0.26	0.0026	0.09	0.013
1000	6.5	0.25	0.14	0.36	0.0027	0.10	

*As found by Walker (9).

These results show very clearly the relation of these factors to the assimilation of phosphoric acid by the cane and indicate the practical possibilities of their application. There is practically no difference in the total P_2O_5 content of the soils at any altitude, the average at 1000 feet being practically as high as at 100. Total lime decreases slightly with altitude which is true of all Hawaiian soils on the mountain slopes. Available silica and phosphoric acid as measured by 1 per cent citric acid solution shows a remarkably consistent relation to assimilation.

SUMMARY

1. There is a definite relation between the availability of silica and phosphoric acid in Hawaiian soils as measured by the response of sugar cane to phosphate manuring.

2. The reaction of the soil and the forms of lime present are also closely related to the availability of phosphoric acid.

3. The applications of these theories to field conditions is shown by the relation of acidity and solubility of silica and lime to the P_2O_5 content of cane juice from cane at Pioneer Plantation.

REFERENCES

(1) HALL, A. D., AND MORISON, C. G. T. 1905 On the function of silica in the nutrition of cereals. *In* Proc. Royal Soc., series B., v. 77, p. 455.

(2) KRAUSE, F. G. 1919 The use of phosphates. *In* Hawaiian Planters' Record, v. 21, p. 14.

(3) MAXWELL, W. 1905 Elements removed from the soil by respective cane varieties. Exp. Sta. Hawaiian Sugar Plant. Assn. Bul. 6, A and C series.

(4) MCALLEP, W. R., AND BOMONTI, H. F. 1922 Clarification. *In* Hawaiian Planters' Record, v. 26, p. 136.

(5) MCGEORGE, W. T. 1923 Phosphate fertilizers for Hawaiian soils and their availability. Hawaii Agr. Exp. Sta. Bul. 41.

(6) PFEFFER, W. 1900 Physiology of plants, 2d ed. Oxford University Press, Oxford.

(7) SCHOLLENBERGER, C. J. 1922. Silica and silicates in relation to plant growth and composition. *In* Soil Sci., v. 14, p. 347.

(8) SHOREY, E. C., FRY, W. H. AND HAZEN, W. 1917 Calcium compounds in soils. *In* Jour. Agr. Res. v. 8, p. 57.

(9) WALKER, H. 1923 Phosphoric acid in cane juices. *In* Indus. Engin. Chem., v. 15, p. 164–165.

A STATISTICAL STUDY OF THE DISTRIBUTION OF SOIL MATERIAL IN THE UNITED STATES ACCORDING TO THE SIZE OF ITS PARTICLES

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Received for publication April 4, 1924

Comparisons are frequently made of the extent of particular soil classes in different regions. Such comparisons are of distinct value but fail to give a definite picture of the size-distribution of soil material since any soil class is composed of particles of varying sizes.

If the area of a soil class is multiplied by the percentages of each of its separates, determined by mechanical analysis, the result is the areas of the separates. If this is repeated with each soil class and the areas of like separates summed, the total area represented by the various classes will then be reduced to the areas of the separates. The area of each separate divided by the total area of all the classes will then give the ratios of the areas of the separates to the total area. This may be stated with greater clearness by using the following algebraic equations:

If $X_1, X_2, \ldots . X_n$ = areas of soil classes in any locality of Area "A,"

And if $a_1, a_2, \ldots . a_n$ = percentage of separate 1 (the coarsest separate in the mechanical analysis) in each soil class,

And $b_1, b_2, \ldots . b_n$ = the percentage of separate 2;

Then $X_1a_1 + X_2a_2 + \ldots . + X_na_n = A_1$

And $X_1b_1 + X_2b_2 + \ldots . + X_nb_n = B_1$

Where A_1, B_1 = areas of separates 1 and 2, respectively.

The ratios A_1/A, B_1/A will furnish points on the size-distribution curve, and by continuing the process for each soil class of a given locality the entire area may be represented by a size-distribution curve.

The number of equations and therefore the number of points on the curve will be equal to the number of separations made in the analysis, while the number of soil classes in the area will give the value of n. If five separations are made in the analysis of each of five soil classes, we will have the following five equations:

$$X_1a_1 + X_2a_2 + X_3a_3 + X_4a_4 + X_5a_5 = A_1$$
$$X_1b_1 + X_2b_2 + X_3b_3 + X_4b_4 + X_5b_5 = B_1$$
$$X_1c_1 + X_2c_2 + X_3c_3 + X_4c_4 + X_5c_5 = C_1$$
$$X_1d_1 + X_2d_2 + X_3d_3 + X_4d_4 + X_5d_5 = D_1$$
$$X_1e_1 + X_2e_2 + X_3e_3 + X_4e_4 + X_5e_5 = E_1$$

The order of procedure, which is entirely arbitrary, is from the coarser to the finer material both in soil class and soil separate. The five equations will completely resolve any area into its component parts. It is to be understood that the average mechanical analysis of a soil class will define that class. It should be emphasized at this point that these equations are general and will apply to any area where the soils have been classified and the method of analysis is known.

When the soils of the United States are considered, it is evident that the method of analysis of the United States Bureau of Soils should be used, and seven equations will then be required.

Since it is physically impossible to differentiate a large number of classes in any area the value of n will be small. Values for the a's, b's, c's, d's, e's, f's, and g's may be found by averaging a large number of analyses of the various classes. Such averages, however, have been made by Whitney (5), and his result have been used in the calculations of this article. It is evident in table 1, page 12 of this bulletin, that 8664 soils distributed in eleven classes have been used to arrive at the average percentages of the classes. The reliability of these averages is confirmed by several hundred additional analyses of the different classes, which failed to show appreciable changes. It should be noted, however, that Whitney's data have been rounded off and that this process has introduced a relatively greater error in the coarser separates.

Each of the thirteen soil divisions outlined by Marbut and associates (3) has been treated by this method. Table 1 is a summary of the areas of the soil classes of the thirteen divisions. Table 2 is derived from table 1 by applying the seven equations to the soil classes in each division as indicated above.

The seven ratios A_1/A, B_1/A, ... G_1/A, as percentages, for each of the thirteen soil divisions, together with their averages, are shown in figure 1 as histograms. Diameters are plotted as abscissa on a logarithmic scale, while the percentage of a separate is represented as an area between its size limits. The value of a particular ordinate is therefore the quotient obtained by dividing the percentage by the number of unit spaces of abscissa defining the separate. The total area under a histogram is 100 per cent.

The data in figure 1 are given in two charts for the sake of clearness, the curve of the average being shown in both to facilitate comparison. The lower limit of clay has been arbitrarily fixed at 50 $\mu\mu$. This is probably justified by recent studies of colloidal material in soils. It is clear, however, that a different lower limit would necessitate a corresponding change in the value of the ordinate of this separate.

Since the curves are weighted by the areas of the various classes, the curve of the mean will also represent the average soil class, which approximates closely a loam; and since the classes of table 1 are representative of a very large number of areas and a very large total area it is not unlikely that the average soil in the United States is a loam. The ratios for the average, as given in table 2, will be designated the "general mean."

TABLE 1

*Areas of individual soil classes for the thirteen Soil Divisions of the United States**

PROVINCE OR REGION	COARSE SAND	SAND	FINE SAND	SANDY LOAMS	FINE SANDY LOAMS	LOAMS	SILT LOAMS	CLAY LOAMS	SILTY CLAY LOAMS	CLAY	TOTAL AREA OF SOIL CLASSES
	acres	*acres*	*acres*	*acres*	*acres*	*acres*	*acres*	*acres*	*acres*	*acres*	*acres*
Atlantic and Gulf Coastal Plain	548,738	4,681,278	6,108,270	7,681,334	19,603,248	5,039,296	2,284,562	2,939,552	433,152	6,744,830	56,064,260
Appalachian Mountain and Plateau	.....	309,766	.....	1,086,829	1,005,696	4,243,868	2,339,584	2,728,144	452,352	751,837	12,918,076
Piedmont Plateau	3,904	6,784	.....	4,531,214	674,304	2,577,093	548,212	975,722	.....	2,667,241	11,984,474
Glacial and Loessial	.....	1,262,536	409,356	1,401,140	1,053,504	6,973,008	13,830,720	3,657,690	17,856	.....	28,605,804
Glacial, Lake, and River Terrace	147,848	778,032	607,102	1,557,944	904,462	2,012,620	604,474	794,240	138,432	1,632,060	9,177,214
Limestone Valleys and Uplands	.....	.....	.....	83,526	9,536	5,284,992	2,318,146	604,660	78,784	532,226	8,911,870
Great Plains	.....	1,003,072	1,264,064	1,758,784	7,869,773	6,760,365	28,968,679	8,441,984	.....	1,460,608	57,527,329
River, Flood, Plains	8,000	131,072	277,568	323,291	1,884,096	1,943,673	4,069,449	250,944	1,203,968	4,895,335	14,987,396
Rocky Mountains	.....	136,960	3,008	284,480	209,664	87,232	159,872	92,992	9,664	135,872	1,119,744
Great Basin	.....	38,100	34,168	238,716	229,516	219,318	.....	282,090	.....	25,600	1,067,508
Arid Southwest	.....	168,192	67,074	217,128	158,428	209,870	24,320	426,193	.....	64,663	1,335,868
Northwestern Intermountain	.....	180,928	189,642	81,216	702,748	465,608	414,086	15,680	.....	15,552	2,065,460
Pacific Coast	77,312	1,442,762	207,746	3,254,416	1,437,378	2,693,208	1,001,081	1,374,537	1,911,168	1,543,356	14,942,964
Grand Total											220,707,967

* Reference to Marbut, *et al.* (3) will show that the areas in this table correspond to the areas upon which soil types have been definitely established.

TABLE 2

Acreage of the seven separates (values of A_1, B_1, C_1, D_1, E_1, F_1, and G_1) in each of the thirteen soil divisions of the United States.

SOIL DIVISIONS	SEPARATES						
	1	2	3	4	5	6	7
	acres	*acres*	*acres*	*acres*	*acres*	*acres*	*acres*
Atlantic and Gulf Coastal Plain	994,318	3,329,548	4,029,202	15,355,480	9,349,655	14,421,615	8,634,353
Appalachian Mountains and Plateau	202,799	617,637	606,169	1,921,884	1,842,011	5,292,852	2,434,725
Piedmont Plateau	282,049	870,380	799,730	2,115,827	1,590,504	3,832,292	2,493,692
Glacial and Loessial	410,269	1,191,437	1,175,039	3,638,155	3,826,998	13,844,096	4,519,810
Glacial Lake and River Terrace	181,296	612,709	663,351	1,921,816	1,269,409	2,823,300	1,705,333
Limestone Valleys and Uplands	143,687	363,486	333,454	1,062,971	1,293,291	4,110,051	1,604,931
Great Plains	705,672	1,880,228	1,708,715	7,388,792	7,739,480	28,697,388	9,407,055
River Flood Plains	169,161	491,344	431,444	1,861,985	1,842,886	6,563,950	3,626,626
Rocky Mountains	21,877	79,485	86,820	235,956	158,929	348,813	187,864
Great Basin	20,411	68,018	72,768	241,135	172,120	314,410	178,646
Arid Southwest	23,653	90,859	106,862	302,979	195,084	385,076	231,355
Northwestern Intermountain	29,556	99,021	126,793	514,208	359,344	678,611	257,927
Pacific Coast	277,815	1,009,074	1,064,965	2,787,650	1,970,609	5,121,076	2,711,785
Totals	3,412,561	10,703,225	11,205,402	39,348,836	31,610,320	86,433,531	37,994,101
Percentage of total area	1.54	4.85	5.08	17.83	14.32	39.16	17.22

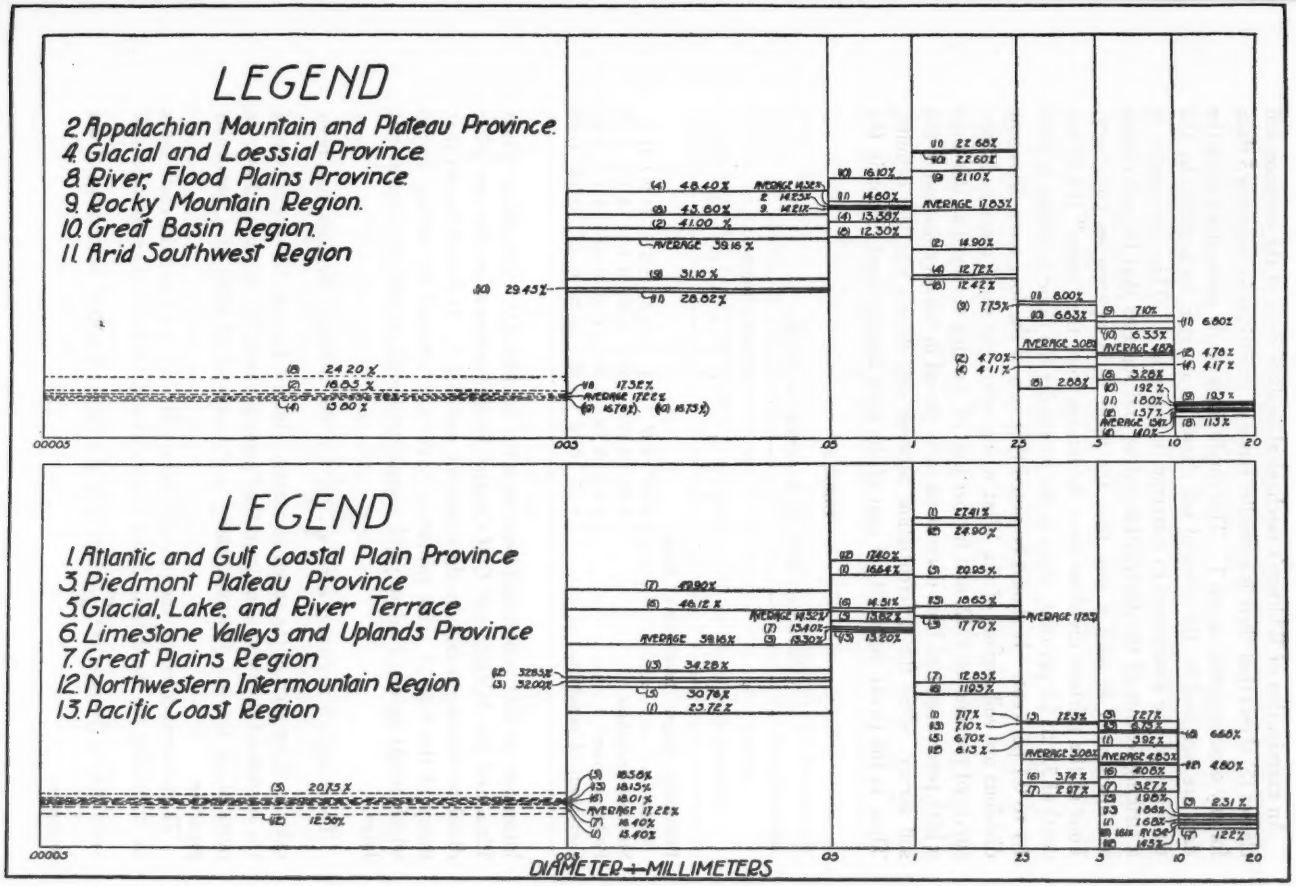

FIG. 1. SIZE DISTRIBUTION CURVES FOR THIRTEEN SOIL PROVINCES

The percentage of each separate is represented by an area between its limiting diameters, which are plotted on a logarithmic scale for convenience. The total area under each curve is equal to 100 per cent.

An examination of Whitney's mechanical analysis data of the common soil classes (5) shows that there is a smaller range of variations for separate 5 than for any other separate except 1. This condition is nearly maintained when the data are weighted by the areas of soil classes in a region, as is shown by the tendency of the histograms to converge in separate 5. This convergence is a striking feature of the distribution curves and suggests that the soil classes are distributed in such a way that the ratio E_1/A approaches constancy. Four of the thirteen divisions show deviations from the "mean" (14.32 per cent) of 3.0 to 1.5 per cent, while in the remainder the same deviation is from 1.1 to 0.1 per cent. It should be noted that two of the four more divergent divisions are soil regions of the West where relatively small areas had been surveyed previous to 1912, and further that of the area surveyed at this time a high percentage had been done at an early period in the organization of the soil survey, when the differentiation between soil classes was less definite. Thus, in the Great Basin 80 per cent of the total acreage used to obtain the

TABLE 3

Statistical criteria for the thirteen soil divisions

	SEPARATE NUMBERS						
	1	2	3	4	5	6	7
Percentage ranges (taken direct from figure 1)	1.18	4.0	5.1	15.5	5.1	24.2	11.7
Standard deviations	0.04	0.28	0.38	3.94	0.58	6.1	1.28
Probable errors	0.03	0.19	0.29	1.95	0.39	4.1	0.86
Coefficients of variability	0.03	0.06	0.09	0.16	0.04	0.16	0.08

histogram of that region had been reported by 1904 (3). The River Flood Plain and the Atlantic and Gulf Coastal Plain Provinces are the two other divisions showing maximum deviations at separate 5. It is well-known that many of the soils of these provinces have been affected by sorting agents which might be expected to yield anomalous results as will be brought out later.

The standard deviation $\sigma = \sqrt{\frac{\Sigma\chi^2 f}{N}}$ for the thirteen divisions has been calculated for each of the seven separates. In this formula $\Sigma\chi^2$ is the sum of the squares of the deviations from the "general mean," N is the total area in acres of all the soil divisions, and f is the number of acres of a particular separate.

The percentage range, the probable errors ($0.6745 \times \sigma$) and the coefficients of variability for the data in figure 1 are given in table 3. The coefficient of variability is the quotient $\frac{\sigma}{m}$ where m is the "general mean" percentage of the separate.

The percentage range, standard deviations, and probable errors are greater for E_1/A(separate 5) than for the same function in the case of any of the first three separates. The coefficients of variability shows, however, that this is due to the smaller acreage of the coarser separate. The standard deviations are shown graphically in figure 2. In the heavy, unbroken curve they have been plotted directly as ordinates, while in the broken line each value of σ is distributed between its size limits by dividing by the number of unit spaces included in its segment of abscissa.

To determine to what extent smaller areas deviate from the "general mean," the individual areas for which detailed survey studies are recorded in the Annual Progress Report of the United States Bureau of Soils for the years 1913–1916, inclusive, were summarized as to soil class and treated by the seven equations. The ratios A_1/A, B_1/A, ... G_1/A were then calculated and compared with the "general mean." These ratios were worked out for 229 areas representing nearly 90,000,000 acres and distributed between thirty-two states. The distribution of the deviations from the "general mean" is shown graphically in figures 3 and 4. The ordinates represent the percentage of the 229 areas having deviations within the range given by the abscissa. The numbers on the curve correspond to the numbers of the separate.

The probable errors for these deviations, calculated from the formula

$$\text{P.E.} = 0.6745\sqrt{\frac{\Sigma x^2}{N-1}}$$

are as follows:

SEPARATES						
1	2	3	4	5	6	7
0.45	1.82	2.39	6.82	2.17	10.82	2.95

In the formula $\Sigma\chi^2$ is the sum of the squares of the deviations from the "general mean," and N is the number of areas considered.

It will be seen that even for small areas the deviations in separate 5 are very much less than in separates 4, 6, and 7, in spite of the fact that the probable errors for small areas are considerably greater than for large areas, as may be seen by comparing these values with the probable errors of table 3. Thus, to take a specific example, the percentage of the areas having deviations within 2 per cent of the "general mean" are as follows:

SEPARATES						
1	2	3	4	5	6	7
98	55	42	15	49	10	36

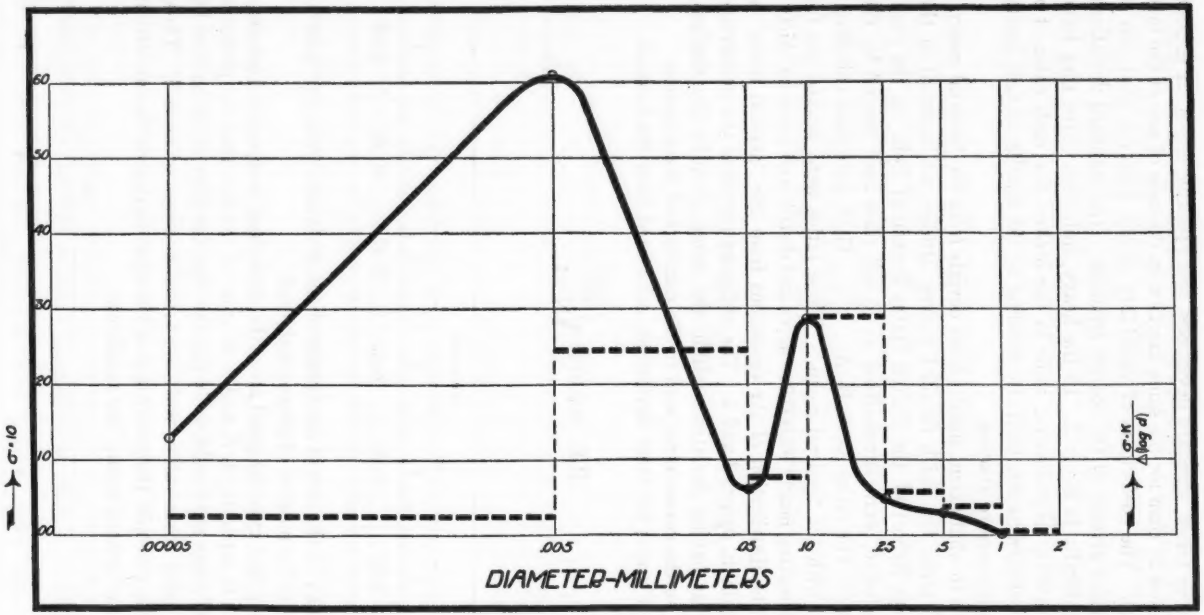

FIG. 2. STANDARD DEVIATIONS FOR THE SEVEN SEPARATES

The abscissa, along which diameters are represented, is divided into seven segments. Standard deviations σ are shown as ordinates in both curves. In the unbroken curve σ for each segment is plotted a point at the smaller end of the segment. In the broken curve, each σ is divided by the number of unit spaces in each segment. The ordinate is $\frac{\sigma}{\Delta \log d}$ (K) where K = 100.

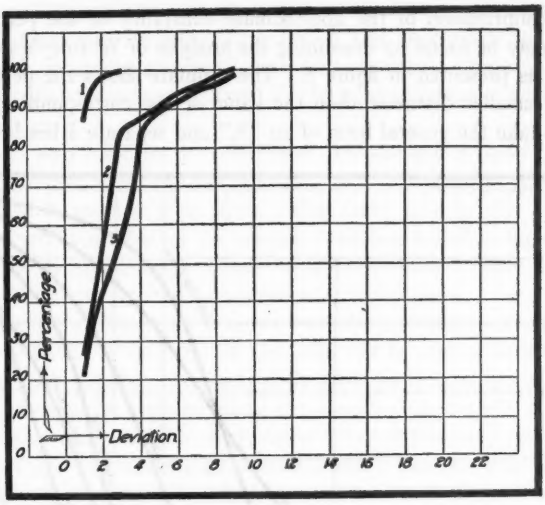

FIG. 3. DEVIATIONS FROM "GENERAL MEAN" FOR SEPARATES 1, 2 AND 3

The ordinates represent the percentage of the 229 areas having deviations from the "general mean" within the range given by the abscissae. The numbers on the curves correspond to the numbers of the separates.

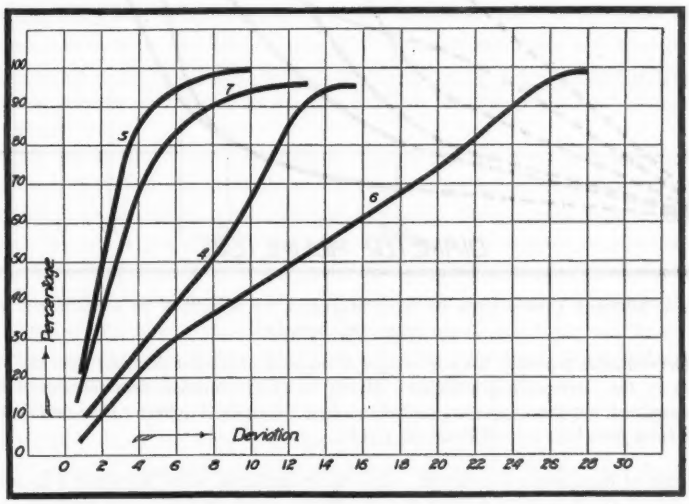

FIG. 4. DEVIATIONS FROM GENERAL MEAN FOR SEPARATES 4, 5, 6 AND 7

The ordinates represent the percentage of the 229 areas having deviations from the "general mean" within the range given by the abscissae. The numbers on the curves correspond to the numbers of the separates.

Further confirmation of the approximate constancy of the percentage of separate 5 may be found by examining the analysis of Whitney's average soil classes (5), as presented in figure 5. The ordinate shows the percentage of material of smaller diameter than the value of the corresponding abscissa. The curves take the general form of an "S," and separate 5 lies between the

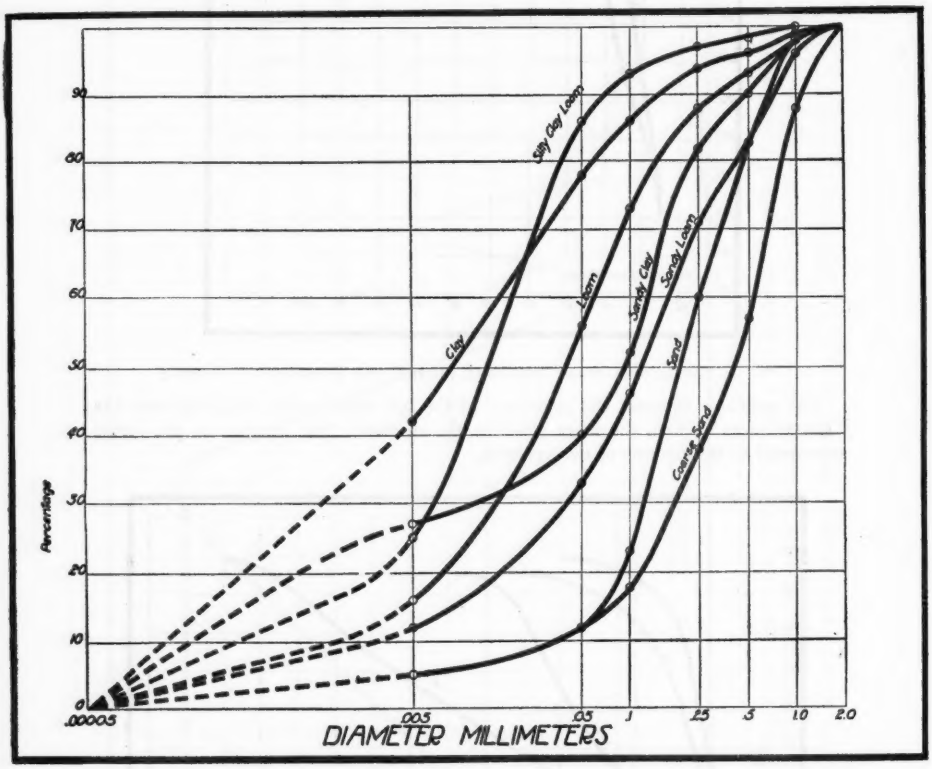

FIG. 5. AVERAGE COMPOSITION OF SOIL MATERIAL AS ANALYZED IN CONNECTION WITH THE SOIL SURVEY

The ordinates represent the percentages of material of smaller diameter than the value given by the corresponding abscissae. Merely to avoid confusion, four soil classes have been omitted, but these types are similar to others shown on the chart. *Data for this figure were taken from table 1 by Whitney (5, p. 12).*

regions of maximum curvature. In coarse-textured soils, separate 5 is nearer the lower bend, and in fine-textured soils near the upper bend, while in soils of intermediate texture it falls near the point of inflection. It will be observed that the segment of the curves representing separate 5 are nearly parallel for all the common soil classes and therefore that the condition that E/A is nearly

constant can be predicted. On the other hand, the segments for separate 4 are nearly horizontal for fine-textured soils and nearly vertical for coarse-textured soils, while the opposite is true for separate 6. Accordingly, it is to be expected that the large variations for different soil classes will be found in these separates.

The chart also indicates that the limit for separate 5 could be extended without materially affecting the ratio of E/A. To establish this rigorously would require a method of analysis giving more data in this region. The value of ascertaining whether the marked variations found in separates 4 and 6 apply over the entire range of these separates is evident, since the region of marked variation would then be located more definitely.

The mode in the histograms of figure 1 usually occurs immediately above or below separate 5. A majority of the soils will be coarse- or fine-textured, depending upon whether the mode is in separate 4 or 6, respectively. In case the ordinates are approximately the same for separates 4, 5, and 6, the soil-class distribution will be about equal between fine- and coarse-textured soils, or in other words will approximate loams. This is confirmed by table 1 and also by the table given by Marbut and associates (3, p. 9) which shows the percentage of distribution of the different soil classes in the several provinces.

It appears, therefore, that there are two extreme types of soil material, one of which weathers to give a maximum ordinate in separate 4, while the other breaks down to a finer state with a mode in separate 6. The explanation of this fact that seems most plausible to the writer is that the relatively hard minerals with poor cleavage remain in the coarser separates and apparently tend toward a mode in separate 4, whereas those minerals which are relatively soft and possess good cleavage go into the finer separates and tend to reach a maximum.

A statement of McCaughey and Fry (4) in this connection is interesting. They say that "certain generalities have been established regarding the composition of these 'mechanical separates' of a soil. Quartz predominates in the coarser separates, while as the diameter decreases there is present in increasing proportions fragments of the softer minerals and those possessing good cleavage, such as kaolinite, the feldspars, etc. It is probably from *a priori* considerations and fro n chemical analyses that the clay separate is richest in such minerals, but this cannot now be definitely proved. On the other hand, ferric hydroxide, alumina, and kaolin also tend to accumulate in the clay."

It is true that quartz predominates in the coarser separates in many soils, and perhaps in most soils, yet there must be important exceptions. The recent work of Hendrick and Newlands (1) shows two important Scottish soil types of thin "glacial drift" origin to be very low in quartz in all the separates examined. The soils were derived from basic igneous rock of the olivine-gabbro type and in the coarse separates carried high percentages of mineral of the orthoclase group (mainly orthoclase and microcline). In other

soils derived from rocks of the syenite type, and even from the granitic type, the coarser separates contained high percentages of the orthoclase group. The quantitative phase of this work was not carried far enough into the fine separates to indicate whether or not there might be a relation between the distribution of the minerals and the size of particles.

The fact that the parent rock is so commonly a mixture of a number of varieties of mineral makes definite proof of the above explanation difficult and in reality a problem in statistics. It is possible, however, that definite tendencies might be indicated by tabulating the distribution of the separates of a number of soil series derived from certain rock types. It is obvious that only residual soils should be used in this connection in order to eliminate as far as possible the action of sorting processes. Table 4 gives the ordinates of the seven separates for a number of important soil series as reported by the United States Bureau of Soils, taking into account all the recorded soil types of each series (3). The ordinates have been calculated as indicated above and described in figure 1. The percentage of the separates may be found from the ordinates by multiplying the ordinates by the following factors which represent the relative distances of abscissa on a logarithmic scale between the limits of the separate.

SEPARATES						
1	2	2	4	5	6	7
3	3	3	4	3	10	20

Table 4 shows that the limestone and slate soils are above the "general mean" in separate 6 and considerably below in separate 4. This condition is reversed in the case of the soils derived from igneous rocks. Soils coming from a mixture of sandstone and shale, on the other hand, give ordinates which are nearly average though tending toward the limestone type of distribution. In this case the shale might be expected to give a high value in separate 6 and the sandstone a high value in separate 4, and the resultant soil to be near an average. It is possible in this case that the shale somewhat predominates, although this cannot be definitely proven.

The Cecil, Durham, and Appling series which are derived from quartz-bearing igneous rocks are considerably above the "general mean" in fine gravel, coarse sand, and medium sand, while the limestone and slate soils are low in these separates.

The data of table 4 indicate in a general way that it might be possible to predict the location of the mode in a histogram of a residual soil area from a knowledge of the parent rock. Before any such application could be made to transported soils the extent of the sorting of the separate by the transporting agents must be known in addition to the rock types. In both cases the maturity of the soil, and perhaps the climate of the region, must be taken into

account. Obviously histograms for soil areas of known rock derivation must first be worked out as a basis for the analogy. This is a task requiring considerable effort. However, it was felt that central tendencies might be indicated by calculating the percentages of the different parent rock-types for a number of the histograms of figure 1. Table 5 is such a calculation based on the rock data given by the United States Bureau of Soils.

In this table the rock types have been divided into four divisions based upon the tendencies to disintegrate into size limits, as indicated in table 4.

TABLE 4

*Ordinates of the seven separates and the kind of rock from which the soil is derived for some of the important residual soils of the United States**

SOIL SERIES	DERIVED FROM	HEIGHTS OF ORDINATES IN SEPARATES						
		1	2	3	4	5	6	7
Alamance	Carolina slates	0.37	0.81	0.54	1.73	3.96	6.06	0.78
Georgeville	Carolina slates	0.35	0.84	0.62	1.87	3.91	5.79	0.87
Crawford	Limestone (pure)	0.39	1.01	0.75	2.13	3.52	4.68	1.37
Colbert	Limestone	0.28	0.80	0.58	2.32	3.95	5.42	0.99
Decatur	Mainly pure hard limestone	0.42	1.34	1.24	3.14	4.62	4.32	1.07
Clarksville	Limestone (cherty) St. Louis to Lower Carboniferous	0.56	1.26	1.22	2.91	4.97	4.82	0.79
Hagerstown	Limestone (mainly pure) Cambro-Silurian Age	0.52	1.33	1.21	2.96	4.65	4.52	0.99
De Kalb	Sandstone and shale (Silurian to Carboniferous)	0.55	1.58	1.50	3.20	4.52	4.67	0.81
Upshur	Sandstone and shale (usually of calcareous nature)	0.54	1.54	1.52	3.92	5.17	4.00	0.92
Iridell	Mainly diorite, hornblende schist, or hornblende gneiss and chloritic rocks	0.48	1.61	1.60	5.05	5.22	3.20	1.06
Cecil	Granite and gneiss	0.81	2.63	2.41	4.60	4.16	2.94	1.14
Durham	Granite and gneiss (rather coarse-grained)	1.22	4.04	3.79	6.40	4.60	2.15	0.60
Appling	Grey schist, hornblende schist, gneiss	1.27	4.08	3.79	6.22	4.50	2.21	0.61
Average for soils of United States as shown in fig. 1...		0.51	1.62	1.69	4.46	4.63	3.92	0.87

* Any ordinate in separates 1, 2, 3, and 5 may be converted to a percentage of the area of the series by multiplying that ordinate by 3; and the ordinates in 4, 6, and 7 by 4, 10, and 20, respectively.

These divisions are as follows: Those that yield a product (1) high in sand and clay but low in silt, (2) approximately average in distribution, (3) high in silt, low in sand, and nearly average in clay, and (4) reworked material whose distribution will depend upon the nature of the sorting agent.

The three bottom rows of figures in table 5 are taken from figure 1. The first two rows give comparisons of the heights of the ordinates using the height of the "general mean" as standard, while the third gives the location of the mode in the histogram. The figures in the main body of the table show the

TABLE 5

Qualitative relation between certain rock types and the content of sands, silt, and clay in the soils derived from them.*

ROCK TYPE	PROVINCES								PRINCIPAL MECHANICAL DIVISIONS
	Piedmont	Appalachian	Limestone Valleys	Glacial and Loessial	Great Plains	Pacific Coast	Atlantic and Gulf Coastal	River Flood Plains	
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	
Granite and gneiss with some schist	72.0	12.8	....	5.3	13.1	17.3	....	....	Sands and clay high, low silt content.
Mainly schist	14.0	1.4	....	....	....	....	....	....	
Diorite and diabase	5.2	....	....	....	....	14.9	....	....	
Sandstone and shale	7.1	77.5	....	....	13.8†	20.5	....	....	Nearly an average distribution
Granite, shale, limestone, and sandstone	....	....	....	41.6	15.2	....	....	....	
Sandstone, shale, limestone, and crystalline	....	....	....	....	....	20.0	....	....	
Sandstone, shale, and limestone	....	6.0	4.3	2.9	10.5†	....	....	....	
Shale and limestone	....	....	....	8.6	12.2	....	....	....	
Limestone	....	....	95.6	....	....	....	26.0	....	High silt content
Loessial material	....	....	....	39.2	32.6	....	2.9	36.3	
Glacial	....	....	....	....	....	26.0	....	3.0	
Reworked residual prairie material	....	....	....	....	....	....	13.7	20.5	
Reworked piedmont appalachian material	....	....	....	....	....	....	57.3	5.5	
Reworked coastal plain material	....	....	....	....	....	....	....	25.5	
Reworked applachian and limestone valleys material	....	....	....	....	....	....	....	9.2	
Miscellaneous	1.8	2.2	....	....	2.6	1.3	....	....	
Separates with ordinates:									
(1) Above average	1–3,7	1,6,7	1,5–7	6	6	1–4,7	1–5	6,7	
(2) Below average	4,5,6	2–5	2–4	1–5,7	1–5,7	5,6	6,7	1–5	
Mode or maximum ordinate	4	5	5,6	6	6	4	4	6	

* The figures in the main body of the table are the percentages of each soil division that has been derived from the different rock types. The percentages are based upon the areas of table 1.

† Soil area, often calcareous.

percentages of each soil division which has been derived from the different rock types.

The table shows that 86 per cent of the Piedmont area, 78 per cent of the Appalachian area, and 100 per cent of the Limestone Valleys area are derived from the rock types of divisions (1), (2), and (3), respectively. Further, it will be seen that the mode is in separate 4 in the Piedmont Plateau, that it is in separate 5 in the Appalachian Mountains and Plateau, and in the Limestone Valleys and Uplands it is in separates 5 and 6. The presence of the mode in separate 5 may not represent the actual distribution. The mechanical analysis data are insufficient for the construction of continuous curves, and the exact location of the mode is not definite. If, however, the curves are smoothed the modes will be shifted towards the left, since the space representing separate 6 is over three times that representing separate 5. This smoothing can best be accomplished by plotting the data as ogives, as illustrated in figure 5. The points of maximum slope on the ogives will give the location of the modes. By this procedure the mode in the Limestone Valleys will be found at approximtely 0.02 mm. diameter and at about 0.04 mm. diameter in the Appalachian.

It is evident that the above location of the mode depends upon the method of plotting the data on a logarithmic scale. If an arithmetic scale were used the mode in all cases of figure 1 would be shifted into the clay. In a previous publication (2) it was shown that if the weight of particles of radius r is plotted as a continuous function of (1) the radius and (2) the logarithm of the radius the relation between corresponding ordinates is given by the expression $W_1 = W_2 \div r$, where W_1 and W_2 are the ordinates associated with unit area under the $W_1 r$ and $W_1 \log r$ curves, respectively.

It can readily be shown that whereas the condition for the mode on the arithmetic scale is $dw/dr = 0$, on the logarithmic scale this condition is $dw/dr = w \div r$. The two modes are therefore not coincident. The selection of the logarithmic scale has been made because of its convenience. However, the $w_1 \log r$ curve may characterize the soil quite as well as the $w_1 r$ curve.

The histograms for the Glacial and Loessial Province and the Great Plains Province are nearly identical. It will be noted that the percentages of the areas of these provinces falling in the three divisions of rock-types do not differ greatly. Thus, 50.7 per cent of the Glacial and Loessial and 55.3 per cent of the Great Plains Area are derived from rock-types of division (3), while the percentages of the areas derived from rock-types of division (2) are 42 for Glacial and Loessial and 29 for the Great Plains. In both of these regions the mode is in separate 6 as is also the mode for the River-Floods-Plain Province. In each of these three divisions a third or more of the area of each is loessial material which is an important factor in giving a high silt content to the area.

The rock-types in division (1) furnish 32 per cent of the soil area of the Pacific Coast region, while those of division (2) furnish 40 per cent. The

mode of this region is in separate 4. Twenty-six per cent of this area is glacial material of unknown derivation. However, judging from the shape of the histogram this 26 per cent would probably be quartz-bearing igneous rock.

The soils of the River-Flood Plain and the Atlantic and Gulf Coastal Plain are largely re-worked material. In the former (see table 1) 70 per cent of the soil is finer in texture than loam, while in the latter (see table 1) 68 per cent is coarser-textured than loam. Sorting of the separates has been carried to an extent that makes distribution studies untrustworthy, but general tendencies might be indicated. The spreading of a stream over its flood plain is accompanied by a deposition of silt and clay, while wave action tends to remove the fine material.

SUMMARY

Histograms representing the average textural composition of the thirteen soil divisions of the United States have been worked out from the data of Bulletin 96 of the United States Bureau of Soils (3).

It was found that the ratio of the area of separate 5 to the total area is approximately constant, for the thirteen divisions. This ratio, expressed as a percentage, is 14.32 ± 0.39. The standard deviation and probable errors are less for separate 5 than for separates 4, 6, and 7, while the coefficient of variability is less for separate 5 than for any other separate except 1. The same relative condition with respect to separate 5 maintains for 229 smaller areas well distributed throughout the United States.

Each histogram was characterized by a mode in either separates 4 or 6 and the constancy of separate 5 is explained on this basis. In order to explain the position of the mode the distribution of the soil from several parent rock-types was studied. It was shown: (1) that quartz-bearing igneous rocks tend to give soils low in silt and high in sand and clay, (2) soils whose parent rock are mixtures of sandstone and shale approximate the average texture, and (3) limestone, slate, shale, and loessial material tend to give soils of high silt and low sand content.

These criteria have been applied to eight of the thirteen soil divisions and offer an explanation of the distribution of soil classes. Sufficient geological and pedological data are not at hand to treat the other five divisions.

It was also shown that the "general mean" which probably represents the average soil class of the United States, is a loam.

ACKNOWLEDGMENT

The author wishes to thank Professor M. D. Thomas for helpful suggestions and criticisms.

REFERENCES

(1) HENDRICK, JAMES, AND NEWLANDS, GEORGE 1923 The value of mineralogical examination in determining soil types, with a method of examination and a comparison of certain English and Scottish soils. *In* Jour. Agr. Sci., v. 13, part 1, p. 1–17.

(2) JENNINGS, D. S., THOMAS, M. D., AND GARDNER, WILLARD 1922 A new method of mechanical analysis of soils. *In* Soil Sci., v. 14, p. 485–499.

(3) MARBUT, C. F., ET AL. 1913 Soils of the United States. U. S. Dept. Agr. Bur. Soils Bul. 96.

(4) MCCAUGHEY, W. J., AND FRY, WILLIAM H. 1913 The microscopic determination of soil-forming minerals. U. S. Dept. Agr. Bur. Soils Bul. 91.

(5) WHITNEY, MILTON 1911 The use of soils east of the Great Plains Region. U. S. Dept. Agr. Bur. Soils Bul. 78.

THE ACTION OF DICYANDIAMID AND GUANYL UREA SULFATE ON PLANT GROWTH[1]

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Received for publication April 10, 1924

INTRODUCTION

In the latter part of the nineteenth century, leaders in agriculture realized that the production of a sufficient supply of nitrogenous fertilizers was becoming a serious problem. It was evident that the problem of meeting the deficiency of nitrogen caused by the removal of crops must find its solution in the vast stores of nitrogen in the atmosphere. In 1895, Frank and Caro succeeded in developing a process by which nitrogen is fixed in a form readily utilized by plants. The new fertilizer, calcium cyanamid, was immediately investigated and was found to be a good substitute for the older nitrogenous fertilizers. However, it was generally observed that its fertilizing value deteriorated greatly in storage, and the probable cause of this was found in the fact that cyanamid readily polymerizes into dicyandiamid as first shown by Beilstein and Gauther in 1862.

More recently new nitrogenous fertilizers are being exploited, among them synthetic urea. During the process of manufacture of urea from calcium cyanamid a small quantity of cyanamid polymerizes into dicyandiamid which, in the presence of sulfuric acid, takes up a molecule of water to form the strongly alkaline dicyandiamidin. This combines with the sulfuric acid to give dicyandiamidin sulfate, more commonly known as guanyl urea sulfate. The reactions may be represented as follows:

$$\underset{\text{Cyanamid}}{2CH_2N_2} \rightleftarrows \underset{\text{Dicyandiamid}}{C_2H_4N_4}$$

$$\underset{\text{Dicyandiamid}}{C_2H_4N_4 + H_2O} \rightleftarrows \underset{\text{Dicyandiamidin}}{C_2H_6N_4O}$$

$$\underset{\text{Dicyandiamidin}}{2C_2H_6N_4O + H_2SO_4 + 2H_2O} \rightleftarrows \underset{\text{Dicyandiamidin sulfate}}{(C_2H_6N_4O)_2 \cdot H_2SO_4 \cdot 2H_2O}$$

These impurities constitute from 1 to 10 per cent of crude urea, and it is essential that we know to what extent they lessen its fertilizing value.

[1] A thesis submitted to the faculty of Rutgers College and the State University of New Jersey in partial fulfillment of the requirements for the degree of Master of Science.

Paper No. 176 of the Journal Series, New Jersey Agricultural Experiment Stations, Department of Soil Chemistry and Bacteriology.

HISTORICAL

Most of the investigations with dicyandiamid and its salts have been carried on in the European countries where the necessity of using calcium cyanamid was more urgent. Since the work of Gerlach (4) and Wagner and Gerlach (5), who first discovered the toxic effects of dicyandiamid, several men have touched upon this subject in connection with their cyanamid investigations but have left meager and contradictory information.

Seelhorst and Müther (30) were the first to give any definite information regarding the action of this compound. They found that in sand it killed the young plants, while in loam soil the plants grew normally except for the drying of the leaf tips, an injury which following investigators have found to be characteristic. Sjollema and Ruijter de Wildt (31) showed that dicyandiamid had no injurious influence on germination, but caused later ill effects in pot experiments with mustard and barley.

Perotti (23) (24) (25) did the first systematic work in testing the fertilizing value of dicyandiamid and its salts in pots and in culture solutions. He found that solutions containing 2.5 parts per 1000 had no injurious effect, but injury was observed when the concentration reached 3 or 4 parts per 1000. In pot experiments 1 gm. in 1400 gm. of soil gave a considerable increase in yield and he concluded that the fertilizing value of calcium cyanamid depends on its polymerization into dicyandiamid in the soil. More recent work, however, does not justify this conclusion. Guanyl urea sulfate and chloride produced no injury in soil when applied at the rate of 350 to 450 pounds per acre, but in 1 per cent solutions toxicity was observed. These compounds were readily converted into ammonia in the soil. Similar views were held by Ulpiani (36). He maintained that the poisonous action of cyanamid is destroyed by the formation of dicyandiamid and urea, which are converted to ammonia and nitrate in the soil. He did not consider these intermediate products injurious in the amounts at which nitrogen is usually applied. However, de Grazia (6) reported almost no nitrate formation from dicyandiamid in soil. This fact was further demonstrated by Löhnis and Sabaschnikoff (10). They inoculated solutions of dicyandiamid with soil, but never succeeded in producing ammonia from concentrated or dilute solution.

Loew (15) (16) compared the action of dicyandiamid in sterilized and unsterilized soil, and found that on sterilized soil the yield compared favorably with that given by ammonium sulfate, while on unsterilized soil growth was seriously interfered with. This was attributed to the formation of injurious compounds from dicyandiamid through bacterial action. This conclusion is not borne out by the work of Löhnis and Moll (17) and the writers cited above, who showed that bacteria do not attack dicyandiamid. Loew observed the characteristic tip drying on both sterilized and unsterilized soil, and suggested that it was due to an excessive accumulation of dicyandiamid in that part of the plant. In 5 per cent culture solutions, severe injury was produced in two days, while in 0.05 to 0.1 per cent solutions the plants developed normally except for the dried tips.

Popp (27) (28) found no injurious effect on germination from dicyandiamid, but plants were not able to utilize it and those plants which took it up made less growth than those without nitrogenous fertilizer. Cyanamid containing 6.5 per cent of this impurity produced considerable injury. The results of Aso (1) are quite the opposite. He obtained injury from an application of 5 gm. per 10 kgm. of soil, but in smaller quantities when applied three weeks before planting no injury was apparent and the yield was almost equal to that of ammonium sulfate and cyanamid. In culture solutions 0.01 per cent dicyandiamid was a source of nitrogen for higher plants. Inouye (8) also found it a good source of nitrogen in pot experiments with barley and rape, when applied at the rate of 0.5 gm. per 8 kgm. of soil. Stutzer (33) and Stutzer and Reis (34) were unable to get an increased yield from dicyandiamid but no injury was produced if other available forms of nitrogen were present.

In the investigations of Brioux (20), Milo (21), and Söderbaum (32) dicyandiamid produced the characteristic injury to the leaf tips when applied as the sole source of nitrogen, and increasing applications resulted in decreasing yields.

Liechti (12) and Liechti and Truninger (13) conducted experiments with spoiled calcium cyanamid and obtained injury which they ascribe to the dicyandiamid contained, but this injury could be overcome by an application of readily assimilable nitrogen. Truninger (35) confirmed the results of Löhnis and others concerning the stability of the compound in soil, and even in the following year secondary ill effects on crop growth were observed in the soils which had been treated with dicyandiamid. Linter (14) also observed this stability during his investigations.

In the pot experiments of Voelcker (37) (38), dicyandiamid was not only unavailable, but depressed the yield of barley and mustard, indicating that it is somewhat injurious, although not to the extent generally alleged. He did not consider the small amounts present in ordinary nitrolin deleterious to the value of the fertilizer. However, it has not been unusual in cyanamid investigations to find samples in which 30 or 40 per cent of the nitrogen was in the form of dicyandiamid. The results of Pfeiffer and Simmermacher (29) indicate that it should not constitute more than 10 per cent of the total nitrogen. In combination with cyanamid they applied dicyandiamid to the soil in increasing amounts from 10 to 100 per cent of the total nitrogen applied. Each pot containing 15 kgm. of soil received 1.5 gm. of nitrogen. Applications above 0.16 gm. of dicyandiamid nitrogen per 15 kgm. of soil resulted in increased injury to the plants and reduction in yield. Germination was not affected by the highest application.

The results of Maze and Lemoigne (19) with culture solutions are similar to those obtained by Stutzer (33) in the soil. They grew corn in culture solutions containing 0.162 gm. of dicyandiamid per liter. When used alone it was unavailable, but in combination with nitrate of soda the plants made normal growth, thus indicating that the compound is not toxic. This conclusion is somewhat confirmed by the work of Johnson (9) (10) who found no appreciable injury from urea containing 33 per cent dicyandiamid, and concluded that the action of the compound is dependent primarily on the concentration in which it is applied.

Probably the most extensive investigation on the action of dicyandiamid is the recent work of Cowie (3). He studied the effect of small and large applications on plant growth and on biological activities in the soil. The compound itself was not decomposed in the soil, nor did it inhibit the decomposition of cyanamid and dried blood, but it did stop the nitrification process when present even in small quantities. The number of bacteria which developed on gelatin plates was in no way affected. In pot experiments the maximum application did not affect germination, but produced a marked toxicity later. Smaller quantities, 12.5–18 mgm. per kgm. of soil produced neither stimulation nor depression, although the characteristic injury to the leaf tips was present.

Mitscherlich (22), Meyer and his associates (35, 36), Hovermann and Koch (7), von Dafert and Miklauz (39) and others have observed injury from cyanamid containing relatively small amounts of dicyandiamid. Lemmermann (11) states that nitrolin should not contain more than 7 per cent dicyandiamid if it is to be acceptable as a fertilizer. His ammonification tests showed this compound and its sulfate and nitrate salts to be very stable in the soil.

While the majority of investigators have expressed an opinion that such small quantities of dicyandiamid and guanyl urea sulfate are not injurious, the results of other investigators cannot be overlooked. With the purpose of determining the effect of these small quantities the following experiment was undertaken.

THE PROBLEM

The object of this work was to determine the influence upon plant growth and microbiological activities of such quantities of dicyandiamid and guanyl urea sulfate as would be applied to the soil in a crude urea fertilizer, and to study the chemical transformation of these compounds in the soil.

GENERAL PLAN OF EXPERIMENT

Throughout the experiment, chemically pure dicyandiamid and guanyl urea sulfate were used, their analyses corresponding to the formulas given above. The investigations carried on may be divided into five parts:

1. The effect on germination.
2. The effect on plant growth in soil.
3. The effect on plant growth in culture solution.
4. The effect on microbiological activities in soil.
5. Chemical transformation of the compounds in soil.

EFFECT ON GERMINATION

Several investigators have reported no injury to germination through the action of these compounds when thoroughly mixed with the soil. In order to give a more rigid test in this experiment the compounds were distributed in the row in direct contact with the seed. Germination boxes of galvanized iron with dimensions 3 feet x 3 inches x 4 inches were sectioned off with strips of tin into 6 inch lengths, and were filled with sand. Twenty kernels of corn were placed in a row in each section directly on top of the fertilizer and covered with 1 inch of sand. Dicyandiamid and guanyl urea sulfate were applied as graduated percentages of the urea applied, ranging from 2 to 15 per cent of the total nitrogen application. The application per section was 0.4 gm. of nitrogen, based on an application of 180 pounds sodium nitrate per acre distributed along sixty rows 209 feet long. The sand was maintained at 50 and 75 per cent of its water-holding capacity. The number of seeds germinated was counted daily and observations on the appearance of the seedlings were made for one week. The results given in table 1 show that in no case was germination inhibited or retarded by the presence of dicyandiamid or guanyl urea sulfate, nor were the one week seedlings in any way affected.

VEGETATION STUDIES IN SOIL

This experiment was conducted in order to determine the effects of dicyandiamid and guanyl urea sulfate on plant growth, and upon the efficiency of urea containing graduated percentages of these compounds. Nine-pound portions of Collington fine sandy loam deficient in nitrogen were placed in pots and fertilized with lime, acid phosphate and muriate of potash, and a total nitrogen treatment of 0.1266 gm. per pot or the equivalent of 375 pounds of sodium nitrate per acre. Urea and the toxins were added from stock solutions and thoroughly mixed with the soil. After seeding to barley on February 24, the pots were maintained at equal and optimum moisture content by weighing and watering the individual pots daily.

Two weeks after germination each pot which had received dicyandiamid, even the smallest quantity, showed slight tip drying, but in no case did guanyl urea sulfate have this effect, even in those pots which had received this sub-

TABLE 1

Effect of dicyandiamid and guanyl urea sulfate on germination

NUMBER	TREATMENT	NITROGEN SUPPLIED BY VARIOUS MATERIALS	WEIGHT OF MATERIAL ADDED	50 PER CENT SATURATED				75 PER CENT SATURATED			
				Number of seeds germinated				Number of seeds germinated			
				5 days	7 days	9 days	10 days	4 days	5 days	6 days	7 days
		per cent	*gm.*								
1	Control		0.0000	16	20	20	20	20	20	20	20
2	C. p. urea		0.2750	7	20	20	20	3	20	20	20
3	$NaNO_3$		0.8440	0	12	19	20	5	19	19	19
4	$(NH_4)_2\ SO_4$		0.6330	0	5	17	18	0	5	17	17
5	$NH_4\ Cl$		*	0	0	2	6	0	0	3	9
6	Dried blood		*	0	0	0	5	0	1	3	3
7	C. p. urea	98	0.2695	0	11	17	20	1	16	20	20
	Dicyandiamid	2	0.0038								
8	C. p. urea	96	0.2640	0	17	19	19	3	19	20	20
	Dicyandiamid	4	0.0077								
9	C. p. urea	94	0.2585	2	19	19	19	8	17	20	20
	Dicyandiamid	6	0.0116								
10	C. p. urea	92	0.2530	8	20	20	20	2	18	20	20
	Dicyandiamid	8	0.0165								
11	C. p. urea	90	0.2475	15	20	20	20	2	17	20	20
	Dicyandiamid	10	0.0194								
12	C. p. urea	85	0.2338	5	17	20	20	4	14	20	20
	Dicyandiamid	15	0.0285								
13	C. p. urea	98	0.2695	8	17	19	19	8	19	20	20
	G. u. sulfate	2	0.0075								
14	C. p. urea	96	0.2640	8	20	20	20	8	18	20	20
	G. u. sulfate	4	0.0150								
15	C. p. urea	94	0.2585	7	18	18	18	8	20	20	20
	G. u. sulfate	6	0.0225								
16	C. p. urea	92	0.2530	8	16	20	20	5	18	20	20
	G. u. sulfate	8	0.0300								
17	C. p. urea	90	0.2475	12	19	20	20	3	13	19	20
	G. u. sulfate	10	0.0375								
18	C. p. urea	85	0.2338	13	19	20	20	0	11	15	17
	G. u. sulfate	15	0.0562								

*Containing 0.1266 gm. nitrogen.

TABLE 2

Effect of Dicyandiamid and guanyl urea sulfate on plant growth and on the efficiency of urea as a fertilizer

NUMBER	TREATMENT	NITROGEN SUPPLIED BY VARIOUS MATERIALS	MATERIAL ADDED	DRY WEIGHTS AVERAGE OF DUPLICATES	INCREASE OVER CHECK
		per cent	*gm.*	*gm.*	*gm.*
1	Control		0.0000	8.42	.....
2	Sodium nitrate		0.8440	19.57	11.15
3	Ammonium sulfate		0.6330	19.05	10.63
4	C. p. urea		0.2750	19.87	11.45
5	C. p. urea	99	0.2722	20.16	11.74
	Dicyandiamid	1	0.0019		
6	C. p. urea	98	0.2695	19.89	11.47
	Dicyandimid	2	0.0038		
7	C. p. urea	97	0.2667	19.43	11.01
	Dicyandiamid	3	0.0058		
8	C. p. urea	96	0.2640	20.14	11.72
	Dicyandiamid	4	0.0077		
9	C. p. urea	94	0.2585	20.22	11.80
	Dicyandiamid	6	0.0116		
10	C. u. urea	92	0.2530	21.75	13.33
	Dicyandiamid	8	0.0165		
11	C. p. urea	90	0.2475	20.01	11.59
	Dicyandiamid	10	0.0194		
12	C. p. urea	99	0.2722	19.32	10.90
	G. u. sulfate	1	0.0037		
13	C. p. urea	98	0.2695	20.69	12.27
	G. u. sulfate	2	0.0075		
14	C. p. urea	97	0.2667	20.00	11.58
	G. u. sulfate	3	0.0112		
15	C. p. urea	96	0.2640	19.63	11.21
	G. u. sulfate	4	0.0150		
16	C. p. urea	94	0.2585	21.77	13.35
	G. u. sulfate	6	0.0225		
17	C. p. urea	92	0.2530	20.45	12.03
	G. u. sulfate	8	0.0300		

TABLE 2—*Continued*

NUMBER	TREATMENT	NITROGEN SUPPLIED BY VARIOUS MATERIALS	MATERIAL ADDED	DRY WEIGHTS AVERAGE OF DUPLICATES	INCREASE OVER CHECK
		per cent	*gm.*	*gm.*	*gm.*
18	C. p. urea	90	0.2475	20.82	12.40
	G. u. sulfate	10	0.0375		
19	C. p. urea	99	0.2722	21.97	13.55
	Dicyandiamid	0.5	0.0008		
	G. u. sulfate	0.5	0.0018		
20	C. p. urea	98	0.2695	21.95	13.53
	Dicyandiamid	1	0.0019		
	G. u. sulfate	1	0.0037		
21	C. p. urea	97	0.2667	20.97	12.55
	Dicyandiamid	1.5	0.0027		
	G. u. sulfate	1.5	0.0055		
22	C. p. urea	96	0.2640	21.81	13.39
	Dicyandiamid	2	0.0038		
	G. u. sulfate	2	0.0075		
23	C. p. urea	94	0.2585	21.19	12.77
	Dicyandiamid	3	0.0058		
	G. u. sulfate	3	0.0112		
24	C. p. urea	92	0.2530	19.95	11.53
	Dicyandiamid	4	0.0077		
	G. u. sulfate	4	0.0150		
25	C. p. urea	90	0.2475	20.24	11.82
	Dicyandiamid	5	0.0095		
	G. u. sulfate	5	0.0185		
26	Dicyandiamid		0.1940	7.90	0.52
27	G. u. sulfate		0.3755	10.62	2.20

stance as the sole nitrogen treatment. Although this injury persisted in each new leaf formed, there was never any indication that growth was being retarded except in the pots which had received dicyandiamid alone. In these pots the leaves were badly burnt, and the plants were slightly smaller than the controls without any nitrogen treatment. This would indicate that its nitrogen is totally unavailable for plant metabolism, and its entrance into the plant in such large quantities causes certain disturbances which slightly retarded its growth. Hence it may be classed as a weak poison and an undesirable substance which accumulates in the plant and cannot be utilized. Those pots which received guanyl urea sulfate alone gave a slight increase over the check, tending to show that this substance becomes very slowly available as a source

of nitrogen and can by no means be considered injurious. All pots which received urea with graduated percentages of these compounds gave a good growth and were equal in yield to c.p. urea, sodium nitrate and ammonium sulfate. Urea appeared to be slightly superior to both sodium nitrate and ammonium sulfate. It must be borne in mind, when comparing these results with previous cyanamid investigations, that urea contains approximately three times as much nitrogen as does cyanamid. Consequently on an equal nitrogen basis, an application of cyanamid consisting of 10 per cent dicyandiamid contains about three times as much dicyandiamid as an equivalent application of urea containing 10 per cent of this impurity. The results of this experiment are given in table 2.

DICYANDIAMID IN CULTURE SOLUTION

In the preceding experiment, the soil moisture was maintained at 12.5 per cent of the air dry weight, so that each pot contained approximately 500 cc. of

TABLE 3

Effect of dicyandiamid on crop yield in culture solutions

	DICYANDIAMID PER LITER	DRY WEIGHT OF TOPS	DRY WEIGHT OF ROOTS	TOTAL DRY WEIGHT
	mgm.	*gm.*	*gm.*	*gm*
1	Control	7.3445	1.6927	9.0372
2	4.2	7.7727	1.7367	9.5094
3	8.4	5.8985*	1.0806*	6.9791*
4	12.6	7.2602	1.7569	9.0171
5	16.8	7.3632	1.5665	8.9297
6	25.2	7.0920	1.5619	8.6539
7	33.6	6.5245	1.5363	8.0609
8	42.0	7.2162	1.6349	8.8511
9	63.0	7.4077	1.7825	9.1902

*Low yield due to an injury to the roots early in the experiment.

water. Assuming this to be the soil solution, the concentration of dicyandiamid ranged from 4 to 40 mgm. per liter. In the culture solutions this concentration ranged from 4.2 to 63 mgm. per liter. These increasing amounts of dicyandiamid were superimposed on Shive's Best Solution R_5C_2, which provided ample available nitrogen. The usual cultural methods were employed. Soybeans were germinated in sphagnum moss and uniform seedlings were selected. Three seedlings placed in paraffined cork stoppers of quart jars containing the solution constituted a culture. Duplicate controls of Shive's Best Solution and duplicate cultures in each case were kept. The solutions were renewed at intervals of three and one-half days. After six weeks' growth the plants were harvested, dried at 100°C. and weighed. The results shown in table 3 do not show any appreciable difference in any of the treatments. The highest concentration, 63 parts per million, is probably as great as would be found in the soil solution of a soil which had been treated with urea containing 10 per cent dicy-

andiamid. Any toxicity should certainly be brought out in culture solution, since there is nothing to prevent its action. The results confirm those of the previous experiments, that small quantities of dicyandiamid are not injurious if other available nitrogen in present.

MICROBIOLOGICAL ACTIVITIES

Since microbiological activities are an important factor in soil fertility, it is of interest to see in what way these activities are modified by dicyandiamid and guanyl urea sulfate.

An experiment was conducted to determine the influence of these compounds on the number of bacteria and fungi in soil. Varying amounts were added to jars containing 1 kgm. of soil, and were kept at optimum moisture and temperature. The numbers of bacteria and fungi were counted at the start and at two-week intervals for six weeks. Sodium albuminate agar was used for counting bacteria and acid agar media of pH 4.2 for counting fungi. The maximum applications, 1.5 gm. dicyandiamid and 0.75 gm. guanyl urea sulfate, had no appreciable effect on the numbers of bacteria or fungi which developed on agar plates. In view of this fact one would expect no depression of biological activities in the soil as measured by ammonification of dried blood. To test this point, 200-gm. portions of the soils treated as described above were placed in tumblers and to each was added 0.5 gm. of dried blood. After the first and second week the soils were analyzed for ammonia by the magnesium oxide method and for nitrates by the phenol disulfonic acid method. The results given in table 4 are quite striking. Where no dicyandiamid was present, ammonification occurred, but the ammonia was immediately changed to nitrate, giving an increase in nitrate. The smallest application of dicyandiamid, 0.1 gm. per kilogram of soil, stopped the nitrification process and an accumulation of ammonia resulted. Guanyl urea sulfate retarded nitrification slightly but not sufficiently to allow an accumulation of ammonia. Neither substance caused any reduction in ammonia formation. Each figure in table 4 is an average of duplicates.

This marked toxic action of dicyandiamid on the nitrifying organisms is further demonstrated in the following experiment. Twenty milligrams of nitrogen as dried blood were added to 100 gm. portions of soil containing small quantities of dicyandiamid and guanyl urea sulfate, and after one month nitrate determinations were made. Nitrification was reduced from 22.6 to 3.6 per cent by the presence of 1 mgm. of dicyandiamid, while 10 mgm. of guanyl urea sulfate had no appreciable effect. The figures given in table 5 are averages of duplicate treatments.

That this toxic action persists for some time in the soil is shown in the results given in table 6. Small quantities of dicyandiamid and guanyl urea sulfate were added to 100-gm. portions of soil and the soils were kept at optimum temperature and moisture. After nine weeks, 20 mgm. of nitrogen in the form of

TABLE 4

Decomposition of dried blood in the presence of dicyandiamid and guanyl urea sulfate

TREATMENT PER KILOGRAM OF SOIL	N ADDED AS DRIED BLOOD	N PRESENT AS NH_3		N PRESENT AS NO_3	
		After 1 week	After 2 weeks	After 1 week	After 2 weeks
gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
0	0.066	0.0045	0.0047	0.0086	0.0122
Dicyandiamid					
0.1	0.066	0.0234	0.0269	0.0019	0.0018
0.5	0.066	0.0240	0.0285	0.0019	0.0019
1.0	0.066	0.0238	0.0292	0.0020	0.0020
1.5	0.066	0.0241	0.0286	0.0019	0.0019
G. u. sulfate					
0.75	0.066	0.0086	0.0089	0.0078	0.0101

TABLE 5

Nitrification of dried blood

TREATMENT PER 100 GM. SOIL	N ADDED AS DRIED BLOOD	N RECOVERED AS NO_3	PER CENT NITRIFIED
mgm.	*mgm.*	*mgm.*	*per cent*
0	0	0.19	
0	20	4.52	22.6
Dicyandiamid			
1	20	0.72	3.6
2	20	0.68	3.4
3	20	0.65	3.2
4	20	0.52	2.8
5	20	0.51	2.7
6	20	0.50	2.5
7	20	0.50	2.5
G. u. sulfate			
5	20	4.41	22.0
10	20	4.38	21.9

TABLE 6

Nitrification of urea

TREATMENT PER 100 GM. SOIL	N ADDED AS UREA	N RECOVERED AS NO_3	PER CENT NITRIFIED
mgm.	*mgm.*	*mgm.*	*per cent*
0	20	14.5	72.5
Dicyandiamid			
0.2	20	7.4	37.0
1.0	20	1.9	9.5
10.0	20	1.0	5.0
G. u. sulfate			
0.2	20	13.2	66.0
1.0	20	13.4	67.0
10.0	20	10.8	54.0

urea was added to each and incubated for a month. Nitrate analyses at the end of this time showed marked differences. The minimal quantity of dicyandiamid, 0.2 mgm. per 100 gm. of soil, reduced the nitrification of urea from 72.5 to 37 per cent, although nine weeks had elapsed since putting the toxin in the soil. The reduction caused by guanyl urea sulfate is not significant. Since the toxicity of dicyandiamid on nitrification is so marked, it may be asked why nitrification of the urea was not stopped in the pot experiment and thus cause a reduction in yield. The highest application in the pot cultures was 0.0194 gm. per pot or 0.5 mgm. per 100 gm. of soil. This was probably sufficient to retard nitrification considerably, but not enough to cause a lack of available nitrogen at any time. It is also possible that some of the nitrogen was utilized as ammonia, since there is abundant evidence that plants can utilize ammonia as such to good advantage.

TABLE 7

Ammonification and nitrification of dicyandiamid and guanyl urea sulfate in soil

TREATMENT PER KILO SOIL	NITROGEN EQUIVALENT	N PRESENT AS NH_3			N PRESENT AS NO_3 IN GRAMS		
		After 1 week	After 3 weeks	After 8 weeks	After 1 week	After 3 weeks	After 8 weeks
gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
0	0.0000	0.0131	0.0135	0.0143	0.0086	0.0084	0.0087
Dicyandiamid							
0.10	0.0666	0.0131	0.0193	0.0190	0.0062	0.0058	0.0060
0.50	0.3333	0.0180	0.0213	0.0214	0.0061	0.0056	0.0060
1.00	0.6666	0.0175	0.0152	0.0172	0.0055	0.0052	0.0055
1.50	0.9999	0.0180	0.0214	0.0209	0.0048	0.0056	0.0056
G. u. sulfate							
0.75	0.2500	0.0232	0.0247	0.0243	0.0075	0.0074	0.0089

STABILITY OF DICYANDIAMID AND GUANYL UREA SULFATE IN SOIL

Some investigators in the literature cited have reported that these compounds are readily broken down in the soil into ammonia and nitric acid while others have found residual ill effects from them the year following their application. This most important point was given a test in the following way. Dicyandiamid and guanyl urea sulfate were mixed with 1 kgm. of soil in the amounts given in table 7. The containers were covered and were maintained at optimum moisture content. At the stated intervals the soils were analyzed for ammonia and nitrates, so as to follow any decomposition of the compounds. The results tabulated below are in accord with the findings of Löhnis (17) and Cowie (3) and others. After eight weeks only a trace of ammonia and nitrate was present in the soils treated with dicyandiamid, and it is probable that this ammonia was absorbed from the air in the laboratory even though precautions were taken against this. The controls showed a higher nitrate and a lower ammonia content than those containing dicyandiamid. This

may be explained on the assumption that in the former, the ammonia absorbed from the air was changed into nitrate, while in the latter this change was prevented by the presence of dicyandiamid. Guanyl urea sulfate showed a slight tendency to become slowly ammonified and nitrified, as was indicated in the pot experiment in which this substance gave a slight increase in yield.

SUMMARY AND CONCLUSIONS

1. Dicyandiamid and guanyl urea sulfate do not retard or inhibit germination, when applied in small quantities in direct contact with the seed.

2. Dicyandiamid is slightly toxic to plant growth when applied in large amounts as the sole source of nitrogen, but in small amounts it produces no injury except a slight tip burning, when other available nitrogen is present.

3. Guanyl urea sulfate is not toxic to plant growth in comparatively large applications, and becomes very slowly available as a source of nitrogen.

4. Minimal quantities of dicyandiamid stop the nitrification process, but do not retard ammonification. Guanyl urea sulfate retards nitrification slightly but does not affect ammonification.

5. Neither substance affects the number of bacteria and fungi in the soil.

6. Dicyandiamid is very stable in the soil. Guanyl urea sulfate is also comparatively stable, but decomposes to ammonia very slowly.

7. The fertilizing value of urea is approximately equal to that of sodium nitrate, and its value is not lessened if 10 per cent of its nitrogen is in the form of dicyandiamid or guanyl urea sulfate.

REFERENCES

(1) Aso, K. 1909 On manuring with dicyandiamid. *In* Jour. Col. Agr. Imp. Univ., Tokyo, I, no. 2, p. 211-222.

(2) Brioux, C. 1910 Contributions to the study of calcium cyanamid. *In* Ann. Sci., Agron., 3 ser., v. I, no. 4, p. 241–281.

(3) Cowie, G. A. 1919 Decomposition of cyanamid and dicyandiamid in soil. *In* Jour. Agr. Sci., v. 9, p. 113–136.

(4) Gerlach, M. 1904 Preparation and use in agriculture of lime nitrogen. *In* Mitt. Deut. Landw. Gessell, v. 19, no. 8, p. 45–46.

(5) Gerlach and Wagner 1903 Upon the utilization of atmospheric nitrogen. *In* Deut. Landw. Presse, v. 30, no. 42, p. 367.

(6) Grazia, S. de 1908 Nitrification of certain nitrogenous fertilizers. *In* Rend. Soc. Chim. Roma, v. 6, no 2, p. 40–41.

(7) Hovermann, —, and Koch, A. 1916 Diminution of value of crude calcium cyanamid by the presence of dicyandiamid. *In* Jour. Landw., v. 64, p. 317–324.

(8) Inouye, R. 1909 On the application of dicyandiamid as a nitrogenous manure. *In* Jour. Col. Agr. Imp. Univ. Tokyo, I, no. 2, p. 193–196.

(9) Johnson, E. 1918 Influence of dicyandiamid on plant growth. *In* Tidskr. Kemi, v. 15, p. 349–393.

(10) Johnson, E. 1919 Action of dicyandiamid on plant growth. *In* Nord. Jordbruksforsk, no. 6, p. 267–272.

(11) Lemmermann, O. 1919 Investigations on different fertilization questions. *In* Arb. Deut. Landw. Gessell., v. 297, p. VIII and 198; *also in* Exp. Sta. Rec., v. 44, p. 317.

(12) LIECHTI, P. 1916 Fertilizer experiments. *In* Landw. Jahrb. Schweig, v. 30, no. 5, p. 506–508.

(13) LIECHTI, P., AND TRUNINGER, E. 1916 Investigations and valuation of crude calcium cyanamid. *In* Chem. Ztg., v. 40, p. 365–366.

(14) LINTER, E. 1917 Calcium cyanamid and dicyandiamid as vegetation factors. *In* Disc. Konigsberg, Prussia, 1917.

(15) LOEW, O. 1908 Physiological action of dicyandiamid. *In* Chem. Ztg., v. 32, no. 57, p. 676–677.

(16) LOEW, O. 1909 Is dicyandiamid a poison for field crops? *In* Chem. Ztg., v. 33, no. 3, p. 21–22.

(17) LÖHNIS, F., AND MOLL, R. 1908 Decomposition of lime nitrogen. *In* Centbl. Bakt. (etc.), Abt. 2, v. 22, p. 254–281.

(18) LÖHNIS, F., AND SABASCHNIKOFF, A. 1908 Decomposition of lime nitrogen and nitrogen lime. *In* Centbl. Bakt. (etc.), Abt. 2, v. 20, no. 11, p. 322–332.

(19) MAZÉ, P., VILA, —, AND LEMOIGNE, V. M. 1919 Action of cyanamid and dicyandiamid on the development of corn. *In* Compt. Rend. Acad. Sci. (Paris), v. 169, no. 18, p. 804–807.

(20) MEYER, D. 1920 Action of stored lime nitrogen. *In* Ztschr. Landw. Kammer, Schlesien, v. 24, no. 30, p. 676–8.

(21) MILO, C. J. 1912 Lime nitrogen as regards its transformation in soil. *In* Meded. Proefstat. Java-Suikerindus, no. 20, p. 601–634.

(22) MITSCHERLICH, A. 1919 Experiments with various nitrogenous fertilizers. *In* Jour. Chem. Soc., v. 116, p. 143.

(23) PEROTTI, R. 1907 Physiological action of dicyandiamid with reference to its value as a fertilizer. *In* Centbl. Bakt. (etc.), Abt. 2, v. 18, p. 50.

(24) PEROTTI, R. 1909 On the nitrogen assimilation from amides. *In* Centbl. Bakt. (etc.), Abt. 2, v. 24, p. 373.

(25) PEROTTI, R. 1908 Physiological action and fertilizing value of salts of dicyandiamid. *In* Rend. Soc. Chim. Roma, v. 6, no. 7, p. 124–5.

(26) PFEIFFER, T., AND SIMMERMACHER, W. 1917 Action of dicyandiamid on the growth of plants. *In* Landw. Vers. Stat., v. 90, p. 415–430.

(27) POPP, M. 1908 Behavior of lime nitrogen and nitrogen lime in storage and in soil. *In* Chem. Ztg., v. 32, no. 80, p. 972.

(28) POPP, M. 1918 Fertilizer experiments with spoiled calcium cyanamid. *In* Zentbl. Agr. Chem., v. 47, p. 299–307.

(29) SCHNEIDEWIND,—MEYER,—, AND MÜNTER,—. 1918 Comparative fertilizer tests with new nitrogenous fertilizers. *In* Deut. Landw. Gessell, v. 33, p. 168.

(30) SEELHORST,—, AND MÜTHER,—. 1905 Investigations with lime nitrogen. *In* Jour. Landw., v. 53, p. 349.

(31) SJOLLEMA, B., AND DE RUIJTER DE WILDT, J. C. 1907 Test of the new fertilizing materials, lime nitrogen, nitrogen lime and lime niter. *In* Verslag. Landbouwk, Onderzoek. Rijikslandbouwproefstat, 1907, no. 2, p. 5–50.

(32) SÖDERBAUM, H. G. 1910 Pot experiments with new nitrogenous fertilizers. *In* Meddel, Centralanst. Forsoksv. Jordbruksomradet, no. 25, p. 18.

(33) STUTZER, A. 1910 Some observations on the action of lime nitrogen. *In* Mitt. Deut. Landw. Gessell., v. 25, no. 13, p. 194–195.

(34) STUTZER, A., AND REIS,—. 1910 Calcium cyanamid and some of its decomposition products. *In* Jour. Landw., v. 58, no. I, p. 65–76.

(35) TRUNINGER, E. 1916 Analysis of crude calcium cyanamid. *In* Chem. Ztg., v. 40, p. 812.

(36) ULPIANI, C. 1908 Ammoniacal fermentation of cyandiamid. *In* Gaz. Chim. Ital., v. 38, II, no. 4, p. 358–417.

(37) Voelcker, J. A. 1916 Woburn pot culture experiments. *In* Woburn Exp. Sta. Rpt. 1916, p. 19–32.
(38) Voelcker, J. A. 1917 Woburn pot culture experiments. *In* Woburn Exp. Sta. Rpt. 1917, p. 14–25.
(39) Von Dafert, F. W., and Miklauz, R. 1919 Determination of dicyandiamid in calcium cyanamid. *In* Chem. Zentbl., v. 90, no. 4, p. 109–110.

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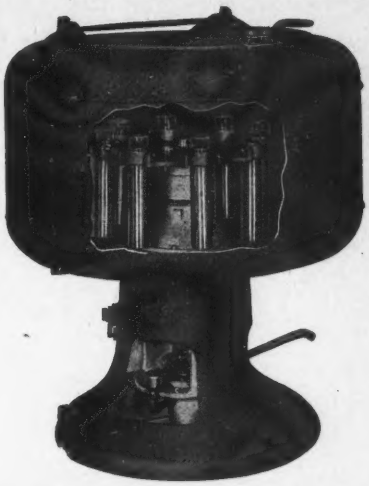

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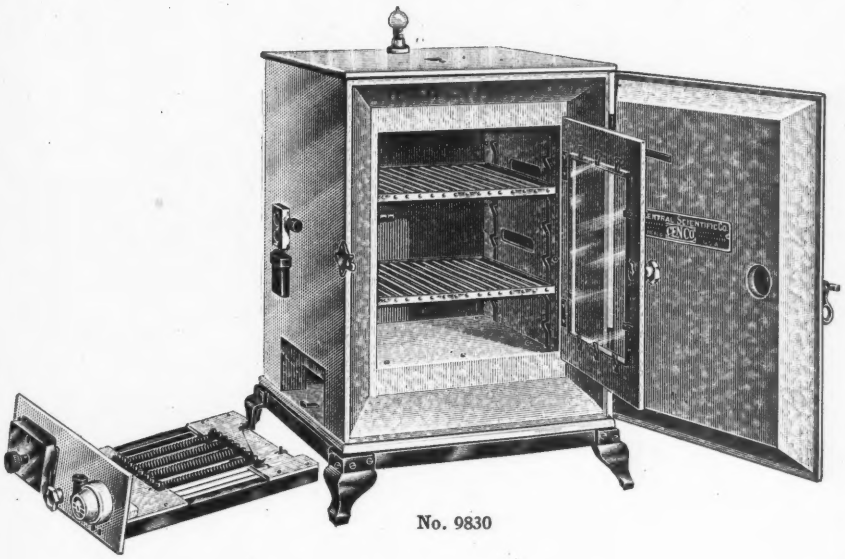

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